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THE RUDIMENTS

OF

HYDRAULIC ENGINEERING.

BY

G. R. BURNELL, F.G.S.,

CIVIL ENGINEER.

With Illustrations.

PART I.

LONDON: JOHN WEALE.

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PREFACE.

HYDRAULIC ENGINEERING.

In the first edition of the "Rudimentary Treatise on Civil Engineering," the plan upon which the whole subject was treated had been drawn up on such principles as to render necessary, in a manner, the discussion of many questions connected with the science of Hydraulic Engineering in the general body of the work. It would, perhaps, be difficult to define exactly the limit of demarcation between the duties of the civil and of the hydraulic engineer, if indeed any distinction between the two professions be recognised; so that even in reproducing the portion of the Treatise especially devoted to the latter division of the subject, in a separate form, much of the original confusion must still exist. An attempt has, however, been made to bring together in the following pages the consideration of the bulk of the subjects especially connected with building in water, or with the applications of that fluid; and, to some extent, to make this Rudimentary Treatise, as far as possible, complete in itself. But it must be observed that, firstly, the discussion of such subjects as those of bridge building would involve a

repetition of a large portion of the work already so well performed by Mr. Law; and, secondly, that the enquiry into the best methods of improving rivers, or of establishing canals, or into the laws of the resistance and movement of fluids, would lead to such an extension of this Treatise, as to render it advisable to depart, in some cases, even from this more recent programme. It is for these reasons, therefore, that the reader is still referred to Mr. Law's "Rudiments of Civil Engineering" for the technical details connected with bridge building; and that Mr. Weale has requested me to devote separate Treatises to some of the other branches of hydraulic engineering whose importance appeared to warrant the distinction; but, nevertheless, it has been my object to render the whole work as uniform and complete, and as free from repetitions, as possible.

It is far from being my intention to claim any merit on the score of the originality of the following pages. Indeed it is more than questionable, whether the author of a Rudimentary Treatise be entitled, under any circumstances, to venture upon the insertion, in such works, of opinions, or of doctrines, which are susceptible of dispute. It is his province to record the universally received theories on the subjects he treats, and he is thus debarred from the expression of opinions which may hereafter be proved to be incorrect. With such convictions then, I have carefully avoided the introduction of controverted doctrines, and have unhesitatingly resorted to the common fund of scientific knowledge to be found in the writings of the most

esteemed authors. Wherever it has been possible the names of those authors have been quoted; but no doubt many involuntary omissions have been made in this respect. The names of the authors consulted in the preparation of this work are, therefore, added in a special Appendix; and the more importance is to be attached to this list, inasmuch as it will (it is hoped) serve to guide the student in his future reading. There is great truth in the maxim, "Scire ubi aliquid invenire possis, maxima pars scientiæ est;" and it may be that the insertion of the Bibliography of Hydraulic Engineering would enable the reader to supply the deficiencies of this work itself. It happens that the majority of the best books on subjects connected with hydraulics generally are written in foreign languages; and perhaps it may be to this fact, that we owe the singular ignorance of educated Englishmen upon the subject. A series of translations, like Mr. Bennett's able translation of d'Aubuisson's Hydraulique, would be of great value, and might induce even our legislators to pause before they meddled with subjects they are apparently so little able to comprehend. In the meantime a mere list of these authors will be of use.

That, in fact, our legislators are often misled in these matters, must be evident to any one who recalls the history of the "Sanitary Movement," as it is called, within the last few years. It would be difficult to say how this unfortunate tendency is to be effectually combated; but, at any rate, it is the duty even of the writer of a Rudimentary Treatise, to call attention to

the most flagrant of the mistaken theories which prevail in high, or authoritative, quarters. In the sections of the following little work devoted to the consideration of town sewerage, and town water supply, an attempt has therefore been made to divert public attention from the incorrect doctrines lately promulgated "by authority" on such subjects, and to direct that attention to the writings of the men who really knew something of the laws (both natural and municipal) which affect those branches of hydraulic engineering. Of course it would be impossible to exhaust such investigations in a merely preliminary treatise; and for this reason again, it has become important to place before the public such indications of the best sources of information, as may enable it to complete what may herein be deficient. The necessity which unfortunately exists for attacking some of the doctrines recently propounded by the very branches of administration which profess to "guide public opinion," may, however, give to some portions of the following work somewhat of a controversial nature. This is much to be regretted; and, as far as possible, I have sought to avoid such discussions, and have only introduced them when it appeared to be absolutely necessary so to do, in order to resist the diffusion of mischievous error. Singularly enough one of the members of a recent ministry was actively concerned in the promulgation, in a neighbouring country, of some of the absurd nonsense with respect to these subjects of sewerage and water supply which has cost us so very dear. It behoves all engineers, then, to record their protest against the

theories and practices so recommended, and to save others, if possible, from the bitter disappointment which they would infallibly encounter if they followed such blind guides. Besides this cosmopolitan motive for alluding to the errors of our rulers, it is now, more than ever, important to induce the public to revert to sound doctrines on many points connected with the application of the physical sciences; for the evil consequences of the mistaken principles lately applied to town sewerage especially, are beginning to produce fearful results. The state of the Thames and of many of our great rivers, indeed, is such as to inspire well-founded apprehension, and also, I fondly hope, an earnest desire on the part of the public to hear any conscientious opinion as to the measures requisite, either for the prevention, or for the remedy of evils so imminent, and so enormous.

In this edition of the Rudiments of Hydraulic Engineering, an attempt has been made to embody our present knowledge of the Chemistry of Building materials with the other portions of the theory of that branch of the profession. This section is, in fact, little else than a condensation of a paper read by myself at the Institute of British Architects, and of an article on Atmospheric influence inserted in the "Dictionary of technical terms," published by the Architectural Publications Society. It is avowedly incomplete; because hitherto very little attention has been devoted to the subject, and there is little satisfactory knowledge thereon to be discovered in the best treatises on Engineering. The insertion of this

section may therefore, it is hoped, call the attention of more able enquirers to an investigation of such vital importance. Of late years also the operations of both English and Foreign well sinkers have thrown so much light on the subject of the internal constitution of the Globe as to render it desirable to extend the short notice originally given upon Artesian wells; and the brilliant success of the operations of the Belgian Government in the irrigation of the Campine, and of the late East India Company in its dominions, has appeared a sufficient justification for the references to them. With all possible care and attention, however, a work of such a wide range as a Rudimentary Treatise on Hydraulic Engineering must ever be incomplete; and, at best, its only merits must consist in the earnest endeavour of its writer to place before the student, in an intelligible form, the truest statement of the universally admitted laws affecting that noble profession.

HYDRAULIC ENGINEERING.

CHAPTER I.

1. The details of Engineering practice which are connected either with the application of water, or with the resistance to its effects, have usually been considered to form part of an important subdivision of the general body of the sciences applied to that profession; and they have been distinguished by the specific name of Hydraulic Engineering. Very strong objections might be raised to this name, for its derivation would certainly indicate that it cannot logically be applied to the bulk of the subjects which it has been made to express; but the use of the word, in the sense referred to, is now so general that there would be danger in attempting to alter it, or to substitute another in its stead. In the following treatise, therefore, the inquiry into the principles of Hydraulic Engineering will be considered to include the discussion of the various questions connected with building in water for whatever purpose, and also of those connected with the use of water commercially, agriculturally, or for municipal requirements. It will thus be necessary to examine, with more or less detail, the principles to be observed in the construction of bridges, canals, docks, harbours, lighthouses, sea walls, &c.; in the execution of works of drainage, warping, irrigation, sewerage,

water supply, river improvement, reclaiming of land, &c.; or, in fact, to investigate the various circumstances under which it may be necessary to resist, to control, or to distribute water.

2. The hydraulic engineer, as the term is above explained, is thus called upon to ascertain the mechanical laws, and the chemical or physical properties of water, and of the various materials exposed to its action. Before, therefore, directing attention to the practical details of the various descriptions of work named above, it is expedient to state briefly the laws and properties thus referred to, or to give a slight sketch of the sciences of hydrostatics, hydraulics, pneumatics, and of some parts of that of applied chemistry.

HYDROSTATICS.

3. Under the generic name of HYDRODYNAMICS are included, firstly, HYDROSTATICS, or the laws of the pressure of water when at rest; and secondly, HYDRAULICS, or the laws of water in movement. Water is considered, in the reasoning usually adopted upon these subjects, to be an incompressible fluid, and its molecules are assumed to exist in a state of cohesion so slight that they are susceptible of being moved in any direction (unless restrained by external objects), without experiencing any sensible resistance. By the addition, or subtraction, of heat water changes its physical condition; becoming, in the former case, an elastic and compressible vapour; and, in the latter, a solid body, subject to all the ordinary laws of such bodies. Hydraulic engineering is principally confined to the operations in which water acts as an incompressible fluid, although occasionally it is essential to take into account the various effects produced by, or attending, its changes of state.

4. Perfectly pure water at its maximum density (which takes place when the temperature is 39·2° Fahrenheit), weighs 62 lbs. 5 oz. per cubic foot; and its specific gravity is usually considered to be represented by that quantity. Above 39·2° water gradually and slowly diminishes in its specific gravity with great regularity; and a similar diminution, but of a more irregular character, takes place when the temperature falls below the point so named. If the specific gravity of water at 39·2° be taken as unity, that of water at 122° will be 0·98758, and that of water at 212° will be 0·95670; whilst the specific gravity of ice itself does not exceed 0·930. It is in consequence of this decrease in the specific gravity of ice, below that of water, that the former rises to the surface, and thus to some extent protects the water beneath it from frost.

5. The salts which are contained in water affect its specific gravity to a trifling extent in ordinary spring or river waters, and to rather a more appreciable extent in those of the sea. Taking distilled water as the type, filtered river water, when free from mechanical impurities, does not differ from it in weight to the extent of more than from 1 to 2 parts in 10,000. Some accurate observations made upon the waters of the Garonne showed that its waters had a specific gravity of 1·00014; and similar observations upon the waters of the Seine gave as nearly as possible the same results. Rivers, such as the Nile during the floods, or the Ganges when at the full, bring down remarkably large quantities of alluvial matter; and indeed it would appear, from the observations of Mr. Piddington, that the mean specific gravity of the latter, as compared to that of pure distilled water, is not less than 1·00153. Sea water is, however, still heavier; its specific gravity is at times 1·028, and a cubic foot weighs 64 lbs. 2½oz.

6. In stating above that water is incompressible, it must be understood that the term is only applied in a practical sense. Water is in fact compressible, but so very slightly, that the diminution under the pressure of one atmosphere is only about 0·000046 of its original volume. It hardly ever happens that the operations of hydraulic engineers are carried on under circumstances to render it necessary to notice this variation in the density of water; and, indeed, insomuch as water does not vary in its specific gravity at ordinary temperatures, or under ordinary mechanical conditions, within a wider range than 0·9984 or 0·999 of its normal gravity taken as unity, there can be no reason for considering it otherwise than as a fluid of a uniform character possessing the following mechanical properties. 1, It is incompressible; 2, its molecules are susceptible of free motion in every direction; 3, it communicates equally throughout its mass, the pressure exercised upon any particular point; 4, in any definite liquid mass any molecule supports in every direction a pressure equal to the weight of a vertical column of similar molecules, starting from it, and continuing to the surface of the liquid. From the latter property of incompressible fluids many important laws of hydrostatics are derived; these are,

a. Every layer, or horizontal film of a homogeneous liquid mass, supports an equal pressure on every part of its surface;

b. The sum of the pressures supported by any horizontal film is equal to the weight of the liquid cylinder or prism, whose base is the surface of the layer, and whose height is the distance from this layer to the upper surface of the fluid mass;

c. The pressure exercised upon any portion of a containing surface, whether horizontal, vertical, or

inclined, is perpendicular to that surface; for the pressure must be resisted by the containing body, and the surface of the latter can only resist perpendicularly to its own direction; the pressure thus exercised is equal to the weight of a liquid column having for its base the portion of the surface under consideration, and for its height the distance from that portion to the surface of the fluid;

d. The pressures being equal upon all the points of the lower horizontal surface of a vessel containing a fluid, the total pressure supported by that surface is equal to that of the column whose base is the surface itself, and whose height is the distance between it and the upper surface of the fluid: so that this pressure would remain the same whatever were the form of the vessel, provided that the area of the bottom, and the height of the liquid did not vary.

7. The above laws furnish the means for calculating the resistances which vases, or containing substances must offer to the pressure exercised upon them by a fluid. Thus: when a vase with a circular horizontal section, small in proportion to the height, contains water, each horizontal ring is pressed, on all its points, by the column of water above it. Now, as in the case when all the points of a circle are equally pressed in an outward direction, the effects of this pressure to force out the containing sides of the circle are proportional to the intensity of the force acting upon each point, and to the radius of the circle itself, it follows that the effort of a fluid to burst a circular vase is proportional to the distance of the ring under consideration from the surface, and to the radius of the vase. Evidently, under these circumstances, the thickness of the containing sides of the supposed cylindrical vase ought to be increased in proportion to the depth

of the fluid, if it were only desired to make them barely in excess of the theoretical dimensions. When the shape of the vase, instead of being cylindrical, is that of a cone with the larger diameter downward, the forces which tend to produce rupture, increase not only with the depth but also with the diameter at the level considered; and in this case the thickness of the containing sides would require to be increased in the lower portions over that which would have been necessary had the vessel been circular, and of the small upper diameter, instead of being conical. If, therefore, in a large vase of this description, a uniform thickness be given which is sufficient to resist the effort exercised upon the bottom, it will be in excess of the thickness absolutely required at the top.

8. In fact, the tangential force exercised by a fluid upon the sides of a vase may be represented algebraically by the simple expression $R\,h$; in which R=the radius, and h=the vertical pressure supported by the surface of the ring. The thickness necessary to resist this force must, therefore, be such as to present a resistance greater than the effort $R\,h$, under any circumstances; whether those circumstances arise from an accidental increase of pressure, or from a diminution of the original resistance of the materials of the vase, by oxidation or by any other cause.

9. It is often necessary to ascertain, not only the total value of the pressure exercised against any definite portion of the surface of a vessel containing a fluid, but also the point of application of the resultant of the various pressures to which that surface may be exposed; for this would evidently be the point to which it would be desirable to apply a resistance which should be able to counteract the first-named forces. This point is known by the term of the "centre of pressure."

10. Now, it must be evident that if the pressures exercised upon the different portions of the surface were co-equal, the centre of pressure would coincide with the centre of gravity of the surface; but as the pressures vary with the distance from the surface of the fluid, the centre of pressure is always below the centre of gravity. It is found, in fact, that the centre of pressure against a rectangular plane surface, whose upper side coincides with the surface of the water, exists upon the line joining the horizontal surfaces, at a distance of two-thirds of its height from the top; or calling x the centre of pressure, l the height of the rectangle measured on the line joining the middle points of its horizontal bases, $x=\frac{2}{3}l$. The centre of pressure of a triangular surface, whose base is horizontal and upon the upper water line, is in the middle of the line joining the summit with the horizontal base; or, $x=\frac{l}{2}$. The centre of pressure of a triangle whose summit is at the water line, and whose base is horizontal and at the lower level, is on the line joining the summit to the middle of the base, and at three-fourths of the distance from that summit; or $x=\frac{3l}{4}$.

11. Should the surface of the bottom of the containing vessel not be horizontal, as it has hitherto been supposed to be, the pressure exercised upon it will be ascertained by multiplying the area into the depth of the centre of gravity of the irregular surface from the upper surface of the fluid. It must be borne in mind, in all calculations of this description, that whatever be the pressure upon the sides of any vessel, ascertained by the laws given above, the pressure upon the bottom is equal to the weight of the whole fluid acting upon it vertically. In close vases, also, if any pressure be applied

to the surface of the fluid they may contain, every proportion of the sides and bottom would be affected by it. It is of the utmost importance that attention should be paid to these laws in calculating the dimensions of constructions intended to hold or to resist the action of large bodies of water, such as reservoirs, sluices, &c.; and it may be convenient to remember, that the pressure of fresh water is nearly 13 lbs. upon every square inch of horizontal surface at the depth of 30 feet, and so in proportion for greater or less depths of water.

12. If still water be contained in vessels communicating freely with one another by means of tubes or passages of considerable dimensions, evidently the equilibrium of pressure cannot exist unless the water stand at the same level in all of them; or, in other words, the pressure arising from the weight of a fluid being proportional to its height, and being equally transmitted in every direction, the surface must always be at the same level in all vases communicating with one another. It is upon this law of the equilibrium of liquids in communicating vessels that the details of works for the connection of reservoirs are calculated.

13. But the law in question only holds good when the communication is of considerable sectional area, and the water is retained in the supposed vessels: when the passage is very small, the equilibrium becomes affected by a new power, known by the name of "the capillary action." This action may, indeed, be observed whenever a body is immersed in water, for the latter either rises or falls round it; and, according as the body may be raised or depressed, the water itself assumes a concave or convex form. There are few substances in nature which do not possess the power of producing this phenomenon: polished steel is however one of the most remarkable exceptions,

and when a bar of that metal is plunged into water, the fluid retains its level at the point of contact with the surface of the steel. But, of course, the effects of capillary action are only feebly displayed when the exposed surface of the fluid is comparatively large; indeed, the very term *capillary action* (or that variation of the ordinary laws of Hydrostatics observable in small tubes whose diameters do not much exceed the dimensions of a hair), implies that it takes effect principally in small tubes.

14. In fact, the energy of the capillary action depends very much upon the form, distance apart, and disposition of the sides of the tubes which excite it. In minute cylindrical tubes, for instance, it is greater than it is in prismatic tubes; and in both descriptions it is greater than when the action takes effect between parallel plates. The elevation, or depression, in cylindrical tubes is in the inverse ratio to their diameter; in prismatic tubes it is in the inverse ratio of the wet contour of the horizontal section; whilst in the case of parallel plates, it is in the inverse ratio of their distance asunder. The surface of the fluid between the plates is perceptibly a demi-cylinder, with a semicircular base, whose axis is horizontal; in a cylindrical tube the surface is that of a demi-sphere, whose diameter is equal to that of the tube itself.

15. Minute as the effects of capillary action may appear to be to a casual observer, they are of the greatest importance in many branches of physical science, and even practically they merit greater attention than they usually receive from engineers, or architects. Thus, for instance, the capillary actions which take place in building materials have a very perceptible influence upon the durability of the latter, and these may be observed to disintegrate the most rapidly at

the limits of the capillary actions. In the cases of sea, or river, walls backed up with earth, the capillarity of the earth causes it to take up water, and thus to become increased in weight; so important, indeed, does this consideration become, when the walls in question are exposed to the influence of tides, that it becomes necessary to allow for the thrust of the earthwork, on the supposition of its being a semi-fluid denser than the earth itself in its dry, or normal, condition. Many failures of wharf, or of retaining, walls have occurred from the neglect of this apparently self-evident law.

16. If a body be immersed in a fluid it is necessary, in order that it may remain in equilibrium, that—1, its weight should be equal to that of the fluid displaced; 2, the centre of gravity of the body and of the displaced fluid should be upon the same vertical line; and 3, the centre of gravity of the body should be as low as possible. The two first conditions evidently result from the fact that the weights of the body and of the fluid act as parallel forces, which can only destroy one another when they are equal and are directed in the same line; the influence of the last condition of stability arises from the law by which the centre of gravity of any body has an invariable tendency to assume the lowest position.

17. When, however, the body, instead of being entirely immersed, floats upon the surface of the fluid, the conditions of equilibrium are virtually the same as they are in the latter case; for the body tends to sink by its own weight, and to rise by the pressure which the fluid exercises upon the portion of its surface submerged—this pressure being evidently equal to the weight of the fluid displaced, and considered to be applied at its centre of gravity. It follows from this, that in order that a body may float upon the surface of

a fluid, its weight must be less than the weight of an equal volume of the latter. Should the body and the fluid actually be in a state of equilibrium, the weight of the fluid displaced must therefore be equal to the total weight of the body; and the centres of gravity of both the liquid displaced and of the body displacing it, must be in the same vertical line. The equilibrium will only be stable when the centre of gravity of the body is lower than that of the fluid displaced by it.

18. In works upon physical science, the term "specific gravity" is used to express the ratio of certain bulks of the substance considered with reference to equal bulks of some other substance of known weight with which they may be compared. Water has been adopted as the standard of comparison in the case of the majority of solids or liquids, on account of its being little exposed to variation, and of its being easily compared with the relative weight of other substances. The specific gravity of gases, or aëriform fluids, is, however, ascertained by adopting the the weight of dry atmospheric air as the standard. It thence follows, that the specific gravity of a solid, or of a liquid, is ascertained by dividing the weight of a portion of such substance by the weight of an equal bulk of water; and, similarly, the specific gravity of a gas is ascertained by dividing the weight of a given bulk of it by that of an equal volume of air. A table of specific gravity is here introduced, but it is particularly to be observed in using such tables, that the ascertaining of the weights of equal volumes of any two substances they may contain depends upon the weight of a definite unit of the term of comparison itself previously ascertained. For instance, if the unit of weight be a cubic inch of water, that of the substance to be compared with it will be found by multiplying the number of cubic inches it may contain by the weight of a cubic inch of water,

and by the tabular number. In the English tables the specific gravity of water is ascertained when it is at 62° Fahrenheit, and when the barometric pressure is equal to that of a column of mercury measuring 30 inches.

TABLE I. OF SPECIFIC GRAVITY OF BODIES (HUTTON AND CARR).

Platina, pure	(Hntton)	23·400	Clay	(Hutton)	2·160
Standard gold	,,	18·888	Brick	,,	2·000
Standard silver	,,	10·535	Common earth	,,	1·984
Cast lead	,,	11·325	Sand	,,	1·520
Quicksilver	,,	13·600	Coal	,,	1·250
Cast copper	,,	8·788	Box wood	,,	1·030
Gun metal	,,	8·784	Sea water	,,	1·030
Cast brass	(Carr)	8·395	Common water	,,	1·000
Iron, cast	,,	7·207	Ash	,,	0·800
Iron, bar	,,	7·788	Maple	,,	0·755
Steel, hard	,,	7·816	Oak	,,	0·925
Tin	,,	7·291	Elm	,,	0·600
Zinc	,,	7·196	Fir	,,	0·550
Glass, flint	,,	3·329			
Glass, white	,,	2·892	Sulphurons acid gas		2·265
Glass, bottle	,,	2·732	Carbonic acid gas		1·500
Serpentine	,,	2·988	Nitrous gas		1·194
Basalt	,,	2·864	Hepatic gas		1·106
Marble	,,	2·741	Oxygen gas		1·103
Granite	,,	2·654	Nitrogen gas		0·983
Porphyry	,,	2·765	Ammoniacal gas		0·600
Flint	(Hutton)	2·570	Hydrogen		0·084
Common stones	,,	2·520	Atmospheric air		1·000

19. The property by which heavy bodies displace a quantity of water equal to their own volume, when their specific gravity exceeds that of the water itself, is usefully applied in calculations of various descriptions, if the specific gravity either of the water, or of the body, be known. Thus, inasmuch as the weight lost by the body when immersed (which may be represented by w) is to its total weight in vacuo (or W) in the same ratio as the specific gravity of the water (or s) is to the specific gravity of the body (S); or in another form as $w : W :: s : S$, it is easy to calculate any one of the unknown terms of the problem, if the others should be already known; or, indeed, as $S = \frac{W}{w}$, the knowledge

of the two latter terms will suffice to determine the others. Again, if a body float on a fluid, the part immersed (Q) bears the same proportion to the whole body (P + Q) as the specific gravity of the body (s) does to the specific gravity of the fluid (S); or $Q : P + Q :: s : S$. It is upon this principle that the *Hydrometer*, or the instrument for ascertaining the specific gravity of fluids, is constructed; for, evidently, when the same body floats on different fluids, the magnitude of the part immersed in the first is to the magnitude immersed in the second, as the specific gravity of the second fluid is to that of the first. The practical rule for ascertaining the specific gravity is as follows:—Let $W =$ the weight necessary to sink the bulb of the hydrometer in one fluid, supposed to be water, and $W \pm w$ the weight necessary to make it sink to the same point in the other. Then, as the specific gravity of water is usually taken as 1·000, the specific gravity of the other will be $= 1{\cdot}000 \times \pm \frac{w}{W}$. When either the magnitude or the weight of a body is given, the other property may be ascertained from its specific gravity, thus:—If the magnitude M, and the specific gravity S, be known, the weight $W = M \times S$; or the weight in grains and the specific gravity being known, the bulk or volume in cubic inches, $B = \frac{W}{252576\ S}$. The magnitude of an irregular solid and the capacity of an irregular vessel may be also ascertained from the property under consideration; for if the solid be weighed in air and in water, then, since a cubic foot of rain water weighs 1000 ounces, it is to the weight lost, as one cubic foot is to the magnitude required; or, again, if the vessel be weighed when empty, and when it is full of water, then the weight of one

cubic foot of water is to the total weight of the water, as one cubic foot is to the total capacity required.

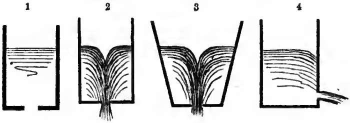
HYDRAULICS.

20. We have seen that when a fluid is contained in a vase of any form, it exercises, in consequence of its gravity, pressure upon every portion of the surface of the vase, and perpendicular to the same. If, then, a vase be perforated, the fluid will escape with a certain velocity; and, at the same time, certain movements will take place in the fluid whilst in the interior of the vase, which we will proceed to notice.

21. When a small hole is made in the bottom of a vase, the molecules of the fluid move vertically to within a short distance of the orifice, supposing the top surface to be exposed to the direct influence of the atmosphere; but the other molecules flow towards the orifice from every direction. If the orifice be on the side of the vase, the molecules of the fluid equally move towards it, as far as the level of the bottom of the orifice itself; so that, in every case, their motion is towards the orifice from every direction; and as the same quantity of fluid must pass through the same space in the same time, if the pressure be uniform, the mean velocity of each such quantity must be in the inverse ratio of the capacity it occupies in the vase.

22. The upper surface of the fluid in a vase, such as we have above considered, is not always terminated by a horizontal plane. Thus, for instance, when the fluid escapes vertically through an opening in the bottom, and the level has fallen nearly to that of the orifice, the upper surface of the fluid assumes the shape of a concave funnel, whose apex is in the centre of the orifice. If the fluid originally had a rotary motion, or if the vase itself were conical, the funnel formed by the upper

surface of the escaping fluid would be developed at an earlier period than if the sides were vertical, and no extraneous motion had been given. If, moreover, the orifice were lateral, the complete funnel-shaped depression would not be formed, but the surface of the liquid would be depressed; as in the accompanying figures, 1, 2, 3, and 4. These movements depend



upon the form of the vases, the height of the fluid in them, and the position and dimension of the orifices. Hitherto mathematicians have not succeeded in explaining satisfactorily the general laws under which they take place.

23. In escaping from an opening in a vase, the fluid-vein assumes the form of a prism, whose base would be the orifice itself, but whose sides recede gradually until they attain a distance from the orifice equal to about half its diameter; at this point, the diameter of the fluid-vein would only be 0·6 or 0·7 of that of the orifice. This diminution in the sectional area of the fluid-vein is known by the name of *its contraction;* and it takes place in whatever direction the fluid may escape, but under slightly different conditions, dependant upon the action of terrestrial gravitation. Thus, when the fluid-vein escapes vertically downwards, the prism contracts to a greater distance than usual, because the velocity of the fall of each horizontal layer increases in proportion to the space fallen through, and therefore the distance between any two such layers

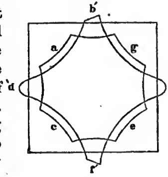
must also increase. Again, when the jet escapes upwards, the prism enlarges immediately after the extreme point of contraction has been passed, because the velocity diminishes. In all cases, however, the resistance of the air divides the jet into drops of greater or less volume, when it has reached a certain distance from the orifice. In vacuo, the jets, if they be not vertical, would describe a parabolic curve in falling, as solid bodies do under similar circumstances.

24. The contraction of the fluid-vein does not appear to arise from any diminution of the volume of the fluid itself, but rather from the fact that the molecules of the fluid leave the orifice with different parallel velocities. Those which pass through the central parts of the orifice are not exposed to the retarding influence of the friction which necessarily takes place upon the perimeter; and they, therefore, must have a greater initial velocity than the molecules which were thus in contact with the sides. Moreover, the velocity of efflux in the filaments of the vein is affected by the various inclinations under which they approach the orifice; in a short time, however, after leaving the vessel the velocity becomes equalised throughout the column, and it would remain constant, if the pressure upon the orifice and the resistance of the air did not interfere with it.

25. When the jet is vertical and downwards, and the liquid has originally a rotary movement, a species of funnel is formed in the interior of the vase, and the liquid leaving it assumes a similar form, but its apex is precisely in the opposite direction to that of the funnel in the interior. If the sides of the orifice be not perfectly even, and the liquid in the interior be impressed with a rotary motion, the fluid-vein, in escaping, often assumes the form and appearance of a

spiral column. When the orifice is polygonal, or of any other than a circular form, the outline of the fluid-vein is more complicated, but substantially the results are not different. If the various parts of the orifice should not be symmetrical, the vein would not retain the form it had on leaving the orifice; but it changes continually as the distance from that orifice increases: thus, immediately after leaving the orifice, the faces corresponding with the rectilineal sides become hollow, and the concavity increases in proportion to the distance; whilst, after a time, the edges corresponding to the angles are splayed off, and finally they disappear altogether. Thus, MM. Poncelet and Lesbros ascertained that the form of the vein, leaving an orifice perfectly square, and measuring 8 inches on each side, presented the section *a, c, e, g*, at a distance of 6 inches from the orifice; and the section *b,′ d, f,′ h*, at a distance of one foot. This last was the smallest section, and its area was 0·562 to 1 of the orifice: whilst the effective discharge was 0·605 to 1 of that indicated by theory. The head of water during the observations referred to was maintained constantly at 5 feet 7 inches. In this case the fluid-vein seems to have made the eighth of a revolution upon its axis; and the researches of Bidone upon the phenomena of jets of water show that many other interesting remarks are to be made upon them. The reader who desires to study the subject is referred to the very interesting work by this author, under the title of "Expériences sur la forme et sur la direction

Fig. 5.



des veines et courants d'eau lancés par diverses ouvertures." For the present it may suffice to observe, that if the jet should be of any important length, a series of contractions and expansions takes place in it; which are accompanied by changes in the transverse section when the orifice is polygonal.

26. The velocity with which a fluid leaves an orifice, observed at the orifice itself, is at the commencement imperceptible; it increases for a certain period, after which it remains constant, if the level of the fluid should continue the same in the vase; or it decreases, if the level should be lowered. Whatever be the form of the opening, or whatever may be its size compared with the transverse section of the vase, so long as the water in the latter remains at the same level, the velocity with which the fluid escapes will follow the same constant law.

27. When the orifice through which water flows from a vessel is made in a thin plate; or when the thickness of the side of the vase does not exceed the smallest dimension of the orifice, and is, at a maximum, only from 2 to $2\frac{1}{2}$ inches; the rate of flow, when no initial velocity exists, has been accurately expressed by Torricelli in the formula

$$V = \sqrt{2\,g\,h}; \text{ from which, } h = \frac{V^2}{2\,g}.$$

In this formula, $V =$ the theoretical velocity; but the real velocity is found to be between $V - 0{\cdot}1\ V$ and $V - 0{\cdot}2\ V$; the diminution of the velocity of the whole jet being attributable to the friction of the water against the sides of the orifice, and to the resistance of the air. In the formula, $h =$ the height of the liquid in the vase above the centre of gravity of the orifice; and $g =$ the acceleration of motion due to gravity, in a second, which is, in London, considered to be $32\frac{1}{6}$ feet.

The velocity in this case is that which a heavy body would acquire in falling in vacuo through h; and as the velocity is proportional to the square root of the height of the liquid above the centre of gravity of the orifice, if the height be quadrupled evidently the velocity will only be doubled.

28. When the liquid flows through an orifice, whose length is $1\frac{1}{2}$ times its smallest transverse dimension, at a minimum; or when an ajutage is employed, whose length is equal to two or three times the smallest dimension of the orifice; the formulæ for calculating the velocity become $V' = 0{\cdot}82\ V = 0{\cdot}82 \sqrt{2\ g\ h}$; V' being the real velocity with which the water flows, and the other notation as before.

29. The velocity would be modified if the two faces of the orifice should be under water, and it would be represented by the formula, $V = \sqrt{2\ g\ h\ (h - h')}$, in which h' = the height of the water in the second recipient, and $(h - h')$ = the difference of levels of the water in the two vessels, retaining the preceding significations of V, g, and h. If the discharging vessel should be subject to any pressure, the formula would become $V = \sqrt{2\ g\ h\ (h + h')}$, in which h' would represent the pressure expressed in the height of a column of the liquid.

30. If we leave out of account the diminution of the velocity, and the contraction of the fluid-vein near the orifice, the theoretical discharge would be $Q = S\,V$, in which Q = the quantity discharged per second, S = the sectional area of the orifice, and $V = \sqrt{2\ g\ h}$. But the quantity which really flows from any orifice differs considerably from that indicated by theory, and it is usually expressed by the formula $Q = K\ S\ V$, in which the new term K = the coefficient of discharge, or the ratio of the real effective quantity flowing from

the orifice to the theoretical one. The value of this coefficient depends upon the pressure upon the orifice, its form, and its position in the sides of the vase.

31. The greatest contraction takes place when the orifice is removed from the bottom, and the sides of the vase, by a distance at least equal to 1 or $1\frac{1}{2}$ times its own smallest dimension; and under these circumstances the contraction takes place all round the fluid vein. But if the sides of the opening should be in the prolongation of the sides of the vase, the ordinary co-efficient of contraction requires to be multiplied by 1·135, in the case when the prolongation exists on one side; by 1·072 when it exists on two sides; and by 1·025 when it exists on three sides. MM. Poncelet and Lesbros have determined the values of the coefficient of discharge for rectangular orifices with the greatest contraction; and these values are given in the Table II. in which the dimensions are given in

TABLE II.

Head over Center.	Height of Orifice.					
	8 in.	4 in.	2 in.	$1\frac{5}{48}$ in.	$\frac{19}{24}$ in.	$\frac{19}{48}$ in.
$\frac{19}{48}$ in.	...	...	...	...	...	0·712
$\frac{19}{24}$ in.	...	...	...	0·644	0·667	0·700
$1\frac{5}{48}$ in.	...	...	...	0·644	0·663	0·693
$1\frac{7}{12}$ in.	...	...	0·624	0·643	0·661	...
2 in.	...	...	0.625	0·643	0·660	...
$2\frac{9}{24}$ in.	...	0·611	0.627	0·642	...	...
$3\frac{1}{8}$ in.	...	0·612	0·628	0·640	...	...
4 in.	...	0·613	0·630	0·638	...	...
$4\frac{3}{4}$ in.	0·592	0·614	0·631	...	...	...
6 in.	0·597	0·615	0·631	...	...	...
8 in.	0·599	0·616	0·631	...	...	...
1 ft.	0·601	0·616	...	...	...	...
1 ft. 8 in.	0·603	0·617	...	...	...	...
3 ft. $3\frac{1}{2}$ in.	0·605	...	...	...	...	...

English feet and inches. They are equally applicable for other forms of orifice, without any inward projection,

provided that the smallest dimension be equal to that of the height given in the table; and they are equally applicable when the discharge takes place in the open air, or under water. It is important, however, to observe that, if all other conditions remain the same, the contraction diminishes in proportion to the thickness of the orifice, for when the latter is considerable it acts to a certain extent as an ajutage; and that when the sides of the vessel are convex, outwardly, the discharge will be increased; whilst, on the contrary, the discharge will be diminished if the sides should be concave.

32. In the sluices of lock gates, the cills of which are generally upon the floor of the lock chambers, the coefficient of discharge is always 0·625, whether the sluice work in still water or not. Formerly, it was usual to adopt the coefficient 0·55 when two sluices were used; but more recent experiments appear to prove that the real coefficient should be, as above, 0·625. With inclined sluices, such as those used in the races of water-mills, with Poncelet's wheels (to be noticed hereafter), the lower and side faces of which sluices are in the prolongation of the reservoir, the coefficient is 0·74, if the upper face should have an inclination of 1 to 2; and of 0·80, if the inclination should be as 1 to 1: the sectional area being obtained from the vertical height of the opening, not from the actual area of the opening itself.

33. When water falls over a weir, its effective discharge is stated by Poncelet to be represented by the formula,

$$Q = K\,L\,H\,\sqrt{2\,g\,H}.$$ In which

Q = the effective quantity falling over the weir;

K = the coefficient of discharge, stated by him to be $= 0{\cdot}405$;

L = the width of the overflow;

H = the height of the water above the cill of the weir; this height must be ascertained at a point where the level of the water is not affected by the contraction of the fluid-vein, which would usually be from 4 to 8 feet above the overflow. In Table III. are given the various coefficients for different values of H, observed by MM. Poncelet and Lesbros; and it further appears from their investigations, that the usual coefficient 0·405 becomes 0.42, when the clear opening of the overflow is of the same width as the leading channel, and when the depth of the latter corresponds nearly with H. If we call the thickness or depth of the sheet of water falling over h, it will be found that $H = 1·178\ h$, when the clear opening of the overflow is $\frac{4}{5}$ths of the width of the feeding channel; and that $H = 1·25\ h$, when the two widths are equal.

TABLE III.

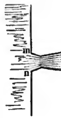
Height over weir	$\frac{19}{48}$ in.	$\frac{19}{24}$ in.	$1\frac{5}{48}$ in.	$1\frac{7}{12}$ in.	$2\frac{9}{24}$ in.	$3\frac{1}{8}$ in.
Value of coefficient...	0·424	0·417	0·412	0·407	0·401	0·397
Height over orifice ...	4 in.	6 in.	8 in.	$8\frac{2}{3}$ in.		
Value of coefficient...	0·395	0·393	0·390	0·385		

34. When cylindrical tubes are added to an orifice in any vase, or reservoir, the discharge through the former will be found to be greater than would have been the case if the orifice had been left in its natural condition, supposing, of course, that the head of water and the dimensions of the orifice remain identical. This increased discharge will not, however, take place unless the water should fill the orifice, and this will occur when the length of the additional tube, or of the *ajūtage*, as it is called, is three or four times its dia-

meter; on the contrary, the orifice will not be filled when the length of the tube is less than that of the contracted vein, produced by the escape of the water. The increase in the discharge produced by a cylindrical ajutage, of the proper length to ensure its being filled, and in which that length does not exceed four times the diameter, is in the proportion of 1·33 to 1·00 of the ordinary discharge through an orifice in the plane sides of the vessel.

35. The effective discharge may be still further increased by making the ajutage of the form represented in the accompanying sketch, provided the liquid fill it entirely. This form of ajutage consists of two portions of cones upon the same horizontal axis, but with their apices in opposite directions. The first portion has the form of the contracted vein; the length of the second is three times that of the first; and the opening m, n, of the first, in the side of the vessel, is $\frac{7}{8}$ths of p, q, of the second. The effective discharge through an ajutage of this form is in the proportion of 3 to 2 of the discharge which would take place through a simple aperture in a thin plate.

Fig. 6.



36. When water flows through long pipes the velocity of its flow is increased by the effect of gravitation, if the pipes have a general fall; and as the liquid column is prevented from changing its form by the adherence to the sides of the pipes, and by the resistance of the air, the lower filaments of the liquid transmit a portion of their velocity to the upper ones, and thus establish a general uniform velocity which increases in proportion to the length of the pipes up to a certain point, beyond which the friction upon the perimeter of the

pipes stops the increase. In horizontal pipes this friction repeated upon a great length tends continually to diminish the velocity; so that, if the length be considerable in comparison with the initial velocity, the liquid might, under some circumstances, hardly flow at all in such pipes. Eytelwein states that, in consequence of the existence of this friction, the head of water, producing motion in a pipe, may be considered to be divided into two parts, one of which serves to generate the velocity, and the other to overcome the friction. This latter portion must, therefore, be directly as the length of the pipe and the circumference of the section (or, as the diameter of the pipe), and inversely as the contents of the section (or as the square of the diameter). This part of the subject will be found treated in greater detail in the subsequent chapter of this work, devoted to the consideration of the water supply of towns; to which it has been reserved on account of its more intimate connection with that branch of practical hydraulic engineering.

37. It used to be considered that the rate of flow of water in pipes was not sensibly modified by the nature of the materials of which they are formed, or by their mechanical structure, so far as regards the smoothness of the interior; and that the flow depended alone on the length and diameter of the pipes. The costly, but, at the same time, the ridiculous, experiments made by the Trial Works Committee of the first Metropolitan Commission of Sewers appeared to confirm this opinion; but, latterly, M. Darcy has seriously called it in question, and from his "Recherches Expérimentales relatives au mouvement de l'eau dans les tuyaux," and from the report of MM. Morin, Combes, and Poncelet, who had been appointed by the Académie des Sciences to. examine the above-named

Mêmoire, it would appear that the nature and the state of the surfaces, over which water flows, exercise a notable influence upon the discharge of pipes. The resistance which the latter oppose to the rate of flow, increases in proportion to the length, and is considered to be in the inverse ratio of the diameter, according to De Prony, and the earlier writers on hydraulics; but M. Darcy's researches throw some doubt also upon the generally received opinions on this point, for he has arrived at the conclusion that the influence of the diameter upon the rate of discharge was greater than would be indicated by De Prony's formula; and that this formula gave results in excess of those actually observed with small diameters, whilst the results were equally below the real fact when large diameters were experimented upon. Under all conditions of the diameter, however, curves, or deviations from the right line, in the pipes have a sensible influence in retarding the velocity of flow. If they should be of a nature to cause a severe shock, it is even possible that they may so effectually disengage the air in suspension in the water as entirely to interrupt the flow, unless a blow-off, or escape for the air, be provided. M. Darcy has devoted a chapter of his work upon the history of the water supply of Dijon, to the discussion of the influence of the air upon the discharge of a pipe, to which we may have occasion to return in a subsequent part of this work.

38. In capillary tubes, as might naturally be expected, the velocity of flow is more affected by the resistance of any confined air than it is in those whose diameter is greater, and the retarding influence of the friction upon the contour is also necessarily more important, because the friction only affects those portions of the liquid which touch the contour of the tubes, and it

must, therefore, be the greatest when that contour is in immediate proximity to the axis.

39. Bernouilli observed that, when liquids flowed in pipes, the pressure they exercised against the sides of the latter, was always less than the pressure they would exercise if they were in repose. The effective pressure is stated by him to be equal to the height of the liquid producing the head at the point observed, diminished by the height of the liquid able to produce the velocity actually existing at that point. From this it will follow, that the pressure will always be in the inverse ratio of the velocity, and that it would be annihilated if the latter were really the velocity due to the head over the point of observation. This law has been verified by a sufficient number of experiments to entitle us to consider it to be correct.

40. In open channels, as contradistinguished from pipes, the fact of the upper surface being open modifies, to a serious extent, the conditions of the flow of any water they may convey; and it has been found that, whatever be the section of a channel, if a uniform velocity be once established in it, the same quantity of water will be discharged at the lower end as enters at the upper; consequently in any transverse section of the channel the same quantity of water must pass in the same period of time. It follows from this, that the velocity of the current must increase in proportion to the diminution of the area of the channel, if the discharge remain the same; on the other hand, that the velocity must diminish in proportion to the increase of the area. As the rate of flow is, in channels, produced by the action of gravitation, it must evidently increase with the inclination; and in order to maintain an equable discharge, the several conditions of the dimensions and of the inclination, both of the channels

and of the water, must co-ordinate. In a channel with a uniform inclination and section, however, the rate of flow also soon becomes uniform; because the friction of the sides destroys the increase of velocity which would otherwise be produced by gravitation—at least this is the case with the inclinations and dimensions ordinarily given to water channels. It also follows, from the effects of the friction upon the wet contour, that the velocity of all the molecules in the transverse section at any point is not equal; those which are in contact with the sides of the channel are retarded in their flow, and, in their turn, they retard the flow of the molecules immediately around them. Of course, under these circumstances the maximum velocity exists at the surface and upon the axis of the current. From the experiments of Dubuat it appears, that the mean velocity of any stream in an open channel, represented by v, may be expressed by the formula $v = c\,V$, in which V represents the velocity upon the axis, and at the surface; and c, a coefficient varying according to circumstances between 0·76 and 0·891. It is usual therefore in practise to consider that, for surface velocities varying between 8 inches and 5 feet per second, $v = \frac{4}{5}V$; or that $V = 1{\cdot}25\,v$. But in large rivers these formulæ would give results far in excess of those actually found to exist; for it has been ascertained that in the Seine $v = 0{\cdot}62V$; and M. de Raucourt found that in the Neva $v = 0{\cdot}75\ V$.

41. The German engineers who have examined this subject, have found that the mean velocity of all the fluid-veins met by the same vertical line in any part of the section of a river, bore a proportion to the velocity at the highest point on that line varying between 0·88 and 0·92. From the experiments made

by M. Defontaine upon the flow of the Rhine, this ratio would appear to be 0·88 in that river.

42. Dubuat concluded from his own observations that the velocity at the bottom of a channel, calling it $U=2v-V$, in which formula v and V retain the same signification as above; and from this, if $V=1{\cdot}25\,v$, $U=0{\cdot}75\,v$; or $v=1{\cdot}33\,U$. In the formation of a water-course therefore, U must be regulated so that its velocity should not be such as to remove the materials of the bed; and Dubuat has drawn up a short table, as follows, of the rate of flow able to carry forward the various substances named :—

	speed per second.	
River mud, semifluid silt	0 ft.	3 in.
Brown pottery clay	0	3¼
Common clay	0	6
Yellow sand loamy	0	8½
Common river sand	1	0
Gravel, size of small seeds	0	4¼
„ „ of peas	0	7⅛
„ „ of beans	1	0½
Coarse ballast	2	0
Sea shingle, about 1 inch diameter	2	2
Large shingle	3	0
Angular flints size of hens' eggs	3	3
Broken stones	4	0
„ agglomerated, or soft schistous rocks	4	4
Rocks with distinct layers	6	0
Hard rocks	10	0

The other dimensions of a water-course would be ascertained from the following formulæ for channels of a uniform inclination and a constant section.

43. In these cases calling Q the discharge, S the sectional area, and v the mean velocity of the water, and

taking the dimensions in yards and the decimal parts of yards, we have $Q = S\,v$; from which we have also $v = \frac{Q}{S}$. The inclination will be ascertained (calling it I) by the formula $I = \frac{P}{S}(av + bv^2)$ according to De Prony. In the latter formula P represents the wet contour, or the developed length of the wetted surface; S, the sectional area as before; and a and b, numerical coefficients which De Prony makes respectively 0·0000444 and 0·000309. Eytelwein was induced, from some observations, to change these coefficients, and to make $a = 0{\cdot}000024$, $b = 0{\cdot}000365$. But it would appear that Eytelwein's values of a and b are only correct for large rivers; whilst for channels whose sectional areas would not exceed 10 yards superficial, De Prony's values are the more correct.

44. If we call the quotient of the transverse section of the watercourse S by the wet contour P, the *mean radius*, and represent it by R, we have $R = \frac{S}{P}$; and the formula of De Prony gives us, replacing a and b by the values he has assigned to them,

$$R\,I = 0{\cdot}0000444\,v + 0{\cdot}000309\,v^2,$$

from which we obtain,

$$v = \sqrt{0{\cdot}005163 + 3233{\cdot}428\,R\,I} - 0{\cdot}07185, \text{ or nearly}$$

$$v = 56{\cdot}86\sqrt{R\,I} - 0{\cdot}072.$$

De Prony's formulæ of course are expressed in French mètres and their subdivisions. Playfair, in his Outlines of Natural Philosophy, translates the last-cited formula for the velocity in English feet as being

$$v = -\,0{\cdot}1541131 + \sqrt{0{\cdot}023751 + 32806{\cdot}6\,R\,I}.$$

From these formulæ it will, therefore, be easy to ascertain the value of v, if I and R be known; or to

ascertain the inclination I requisite to obtain such a velocity that $v = \frac{Q}{S}$. The value of R depends upon that of the section S, and the form of this section; the latter being usually regulated by local considerations. If the channel should be executed in wood or in masonry, it would, generally speaking, be preferable to make the sides vertical, and the width equal to twice the depth of the water so as to render the wet contour, and con-consequently the surface producing friction, as small as possible. In channels of earthwork, or ordinary canals, the slopes of the sides vary according to the nature of the materials employed, and the width usually ranges between four and six times the depth of the water.

45. De Prony's formula for ascertaining the velocity will serve, not only to calculate the discharge of a channel of a uniform inclination and constant section, but also to gauge any stream, provided a length of about 500 yards can be found upon it, where those conditions of inclination and section are fulfilled. A cross-section of the stream will, in this case, give its area and its wet contour, and by dividing the former by the latter the mean radius R will be found; a longitudinal section will give the total inclination of the regular portion of the stream; and this inclination, divided by the developed length of the axis, will give the partial inclination in each unity of length. If the section of the stream should not be constant (which is indeed almost always the case with natural channels), a certain number of cross-sections must be taken in the portion where the stream is most regular, from which an average must be deduced, for the purpose of furnishing the elements for calculating the wet contour and the mean radius. The inclination is then to be ascertained from the mean velocity v, and the discharge

will be found by the ordinary formulæ. Should it happen, however, that the stream is divided into two portions, one of which is very deep and comparatively speaking narrow, whilst the other is shallow and broad, it would be preferable to consider the stream as though it were divided into two distinct branches, and to calculate the discharge of each of them separately.

46. It is possible also to ascertain the volume of a river by determining the maximum velocity of the surface, and the average sectional area; for the discharge will be found to be nearly $Q = S\ (0{\cdot}8V)$ which latter term we found to be the expression for the mean velocity v. It is essential in all such calculations that great care should be taken not only in ascertaining the cross-sections, but also that the floats used to determine the velocity should be thrown into the stream at some distance above the points of observation, in order that they may really acquire the average velocity of the water during their passage.

47. The preceding observations, it must be observed, only apply when the volume of water passing an orifice, or through any given portion of the channel of a stream, is such as to maintain a constant head or pressure. If, however, the discharge should be greater than the supply, the level of the water above the orifice, or section, will fall, and consequently the head or pressure producing the velocity will be reduced. The value of H in such cases will, therefore, have to be modified so as to express the effective head influencing the discharge during the entire operation. It has also been assumed, that the discharge takes place in the open air, and without encountering any resistance on the under side; but in the case of one reservoir discharging its waters into another, not only does H require to be modified, but a new term is required to

be introduced, for the purpose of representing the resistance of the water in the lower reservoir as it rises above the orifice of communication.

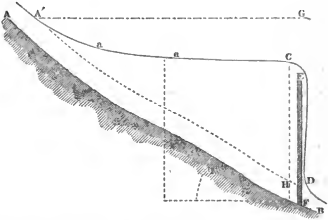
48. Morin gives a rule for ascertaining the discharge when a variable head, as above described, exists over the centre of an orifice, which is sufficiently simple for ordinary practice, and may be stated as follows: A vertical rule is to be placed in the upper reservoir, and upon it are to be measured the levels of the water corresponding to equal intervals of time; for ordinary purposes five observations will suffice. Then, calling L the width of the orifice; E, its height; m, the coefficient of discharge ascertained from the arithmetical mean between the values corresponding with the greatest and least heads observed; h_1, h_2, h_3, h_4, h, the levels corresponding with equal intervals of time t; and Q, the volume discharged in the whole time, or in this case, $4\,t$; we have $Q = 1{\cdot}476\, m\, L\, E\, t\, (\sqrt{h_1} + \sqrt{h_5} + 4\,(\sqrt{h_2} + \sqrt{h_4}) + 2\sqrt{h_3})$: or, in other words, if it be desired to ascertain the volume of water discharged in a given time by an orifice, with a load upon its summit of a variable nature, after having as above observed the variations of level, the rule is—to take the square root of each of the heads over the orifice; to the sum of the greatest and least of these square roots add four times the sum of the square roots of the heads of the even pair of the heads observed, and twice the sum of the square roots of the heads of the uneven pair; multiply the total sum by the time which has elapsed between two observations by the area of the orifice, by the coefficient discharge, and by 1·476. This formula becomes, when the flow of water over a weir is considered, $Q = 0{\cdot}598\ L\ t\,(h_1\sqrt{h_1} + h_5\sqrt{h_5} + 4\,(h_2 + \sqrt{h_2} + h_4\sqrt{h_4}) + 2h_3\sqrt{h_3})$; and when the orifice may be covered with water on the underside,

the heads h_1, h_2, &c., must be replaced by the differences of the heads on the upper and under sides at the same periods of observation; that is to say, h_1 becomes $H_1 - h_1$; and h_2 becomes $H_2 - h_2$, calling H the head producing pressure on the upper, and h that on the under side of the orifice.

49. In all rivers there will be found to exist a greater or lesser extent of comparatively speaking still water in immediate proximity to the bank; and in this part of the stream may also be observed a series of small eddies, produced by the impulsion of the current. The principal direction of these eddies appears even to be opposed to that of the current, and again, when any obstacle is offered to the onward flow of the latter, the water becomes heaped up, as it were, and in this case also a kind of return in the current takes place, owing to the change of direction in the flow of the water. A dyke or embankment in a river will produce this effect; as will also any construction which diminishes the water way, such as groins, bridges, &c. There is no universally received word in the English language which expresses this effect, and it may, therefore be as well to adopt the French word "remous" to express simultaneously the increase of height and the change of direction, produced in a current by the intervention of any obstacle to its flow.

50. In the case of a dam across the whole width of a stream, the horizontal section of whose bed is represented to an exaggerated scale by the line A B, and the dam by E F, the water will rise on the upper side, to fall subsequently over the edge of the dam. The fluid mass represented by A *a a* C D will here represent the remous; and its greatest depth, excepting in so much as it is modified by the conditions mentioned in the next sentence, will exist immediately over the

edge of the dam, E F, and will be derived from the height of the latter, diminished by the original depth



of the water, and increased by the height of water standing on the edge. This last quantity has been ascertained by M. Castel to be represented by the formula $x = 0{\cdot}64\sqrt[3]{\left(\frac{Q}{L}\right)^2}$; in which Q = the volume of the current, and L the width of the dam. Should the water, however, be withdrawn by a series of sluices at the lower part of the dam, instead of falling over its edge, the greatest depth will be equal to the distance between the centre of the openings and the bed, added to the distance between that centre and the top level, which will be found by making $x = 0{\cdot}1805 \frac{Q^2}{A^2}$, A being the sectional area of the openings. But the greatest elevation of the water above the horizontal line does not take place immediately upon the dam; it occurs at a small distance above it. The same thing happens in this instance, which happens in all others in which water flows over a weir, viz., that shortly before the water arrives at the edge, it slopes towards the latter,

and in large remous this sloping, or inclination of the surface, will begin at a considerable distance on the upper side of the dam. The height of the remous, at any given distance from the edge, will necessarily result from the nature of the curve assumed by the surface of the water. This is essentially a hyperbola, whose summit is at A′, whose axis is A C, and which is nearly tangential to a line passing through A, at such a distance that $E\ G = \frac{2\ E\ H}{b}$; in which expression b = the length of the dam.

51. During the investigations conducted by the Italian engineers for the purpose of discovering a simple self-acting gauge to measure the waters supplied for the irrigation of that country, a very interesting and important fact was observed, which indicated that the ordinary laws of hydrostatics applicable to the level of water in communicating vases, were modified to some extent when the water was set in motion. It was then ascertained that, in a vase constantly supplied, but divided into two portions by a diaphragm susceptible of being moved vertically, and with a discharging orifice on one side, a constant difference of level existed in the surfaces of the respective portions of the reservoir so long as the water flowed; and that this difference of level was greater in proportion as the opening of the diaphragm was less, compared to that of the orifice. And it was also observed that if, by any change in the direction of the supply or of the flow, the level were made to alter on either side of the diaphragm, the corresponding variations in the level upon the two sides continued always to be proportional to the respective differences of level first established. This law is not affected by the introduction of two or more diaphragms, for a similar

variation of level takes place between each of them, and it is maintained so long as the water flows. Of course, if the discharge cease, the hydrostatic pressure will cause the water to assume the same level in all the communicating compartments, whatever be their number.

52. If we suppose a fluid to be contained in a reversed syphon, each of whose branches is of the same diameter, the fluid will be found to stand at the same level in both of them; and if, by any means, the fluid column be first raised in one of the branches, and then allowed freely to resume its natural position, it will commence its movement by falling below the original level, in consequence of the velocity acquired; it will immediately afterwards remount above that line, and continue to oscillate about it for a certain time. These oscillations are found to be isochronous; and if the branches of the syphon should be vertical, their duration will be equal to that of the beats of a pendulum, whose length is equal to half the total height of the liquid column.

53. When any point on the surface of a pool of still water is disturbed, a series of small waves is formed around it, which extend with great rapidity. These waves are found to be of two sorts: the first are formed at the same moment in great numbers, and are propagated in every direction with a uniformly increasing velocity, like that of the fall of heavy bodies, and the distance between the summits of any two waves increases in the direct ratio of the time elapsed since their formation; whilst the heights decrease in the inverse ratio of the square of the time, when the liquid is contained in a channel of a constant width—or, according to the fourth power of the time when the liquid is free. The second sort of waves also rises in infinite numbers, and at the same time; but the waves

are propagated uniformly with a velocity proportionate to the square root of the diameter of the surface exposed to the shock; the heights of the surface decrease in the inverse ratio of the square root of the time, or of the first power thereof, according as the liquid may be contained in a channel, or be entirely free. The second description of waves is more appreciable than the first, especially near the point of origin; and any wave which is formed thus on the surface of a liquid mass, is propagated to a considerable depth in the interior.

54. When waves of either of the above-mentioned sorts come in contact with a fixed body, they are interrupted in a portion of their course, and that portion of the wave which strikes the resisting body, is reflected back upon itself, and propagated in a direction opposite to the one it originally followed; it is, however, re-formed beyond the obstacle, if the latter be isolated in the midst of the fluid, and it extends beyond it as though the wave had never been interrupted. When several centres of disturbance are formed in a piece of still water, the respective series of waves may be observed to cross one another without producing any very decided interference. These observations, however, are only applicable to small bodies of water; in the subsequent parts of this treatise, attention will be more particularly called to the laws affecting the formation of the waves of the sea and of their mutual interference.

55. Bodies moving in fluids meet with two species of resistance: the one arising from the movement communicated to the portions of the liquid successively displaced; and the other, from the power necessary to separate the parts of the liquid between which the bodies move. Up to a certain velocity, the resistance

of fluids from the first cause is found to be proportional to their density; to the square of the sectional area of the bodies moving in them, modified to a considerable extent by the forms of such bodies, and to the square of the velocity. The resistance arising from the cohesion of the fluid was found by Coulomb to be proportional to the velocity, and to be independent of the nature of the surface of the body; he also found that the pressure to which the fluid is exposed, is equally without influence upon the value of the resistance. Thus it would appear, that any body moving in a liquid meets with a resistance composed of two terms: the one due to the inertia of the liquid, and increasing as the square of the velocity; the other due to the cohesion of the liquid, increasing simply with the velocity.

56. The researches of Mr. J. Scott Russell upon the movement of canal boats at high velocities, would induce us to believe that when the velocity of bodies of that description exceeds 13 feet per second, some new, and hitherto but imperfectly understood, laws come into operation. Our present knowledge of the subject may, perhaps with some reserve, be thus expressed, in the words of the Report of the British Association for the Advancement of Science.

After establishing the fact that the movement of a canal barge, or of any solid body, in a channel of still water gives rise to a displacement of the water surface, which advances with an undulatory motion in the same direction as the body itself, and which Mr. Russell distinguishes by the name of the *wave of displacement;* he proceeds to say that: "The resistance of a fluid to the motion of a floating body will rapidly increase as the velocity of the body rises towards the velocity of the wave of displacement caused by the said motion,

and it will be greatest when the two velocities approach equality.

"When the velocity of the body is rendered greater than that due to the wave, the motion of the body is greatly facilitated. It remains poised on the summit of the wave in a position which may be one of stable equilibrium; and this effect is such that, at a velocity of 9 miles per hour, the resistance is less than at a velocity of 6 miles per hour behind the wave. The velocity of the wave is independent of the width of the fluid, and varies with the square root of its depth.

"It is established that in every navigable stream there is a velocity at which it will be more easy to ascend against the current, than to descend with the current. Thus, if the current flow at the rate of 1 mile per hour in a stream 4 feet deep, it will be easier to ascend with a velocity of 8 miles per hour on the wave, than to descend with the same velocity behind the wave. The velocity of the wave of displacement (which advances in the direction of movement of the floating body) is about eight miles per hour."

It must not, however, be understood that the conclusions of the British Association in this matter are universally received as correct; for not only have the practical results of the attempts hitherto made to apply the laws thus enunciated been such as to inspire serious doubts with respect to them, but the direct experiments of Generals Morin and Poncelet on the resistance of water to bodies moving in it led those able observers entirely to reject the theories of Mr. Scott Russell upon which those conclusions were founded. M. Bourgois, in a recently published Memoire "sur la resistance de l'eau au mouvement des corps" (Paris, 1857), adopts the views of M.M. Morin and Poncelet; and indeed there seem to be very grave

reasons for believing that, in spite of the merited authority of the members of the British Association, they were in error in supposing that any new laws with respect to the resistance of fluids were to be observed, so long at least as the velocity of movement did not exceed 10 miles per hour. The influence of the bottom and of the sides of a canal, as well as that of the wave of displacement itself, upon the resistance of the fluid to an advancing body, are so great, however, as to render it extremely difficult to discover any precise expression of that resistance, or the laws under which it acts.

57. Projectiles, when they strike the surface of a liquid, meet with a resistance which diminishes their velocity and changes the direction of their path. The intensity and direction of this resistance depend upon the form of the projectile and its velocity. At all times, however, it tends to raise the direction of movement and to carry it towards the surface of the liquid; and if the original direction of the projectile should only be slightly inclined towards the horizontal line, the shock may even cause the projectile to rebound, in the same manner in which it would have rebounded from the surface of a solid body. It is thus that stones, thrown from a small angle, or bullets fired from batteries near the water line rebound, or *ricochet*, a great number of times before their velocity is sufficiently retarded to allow of their sinking permanently below the surface of the water by the ordinary effect of gravitation.

58. When a fluid is in motion a certain portion of the force by which it is animated may be employed for the purpose of driving a machine: but evidently the motive power thus applied, must be only that portion attributable to the gravity of the water itself; for if it

were necessary to create the power by the application of extraneous force, it would evidently be preferable to apply that force directly to the machine itself. In the industrial arts, then, water is only applied as a motive power when it flows in an inclined channel, or when it falls suddenly from a height. But it must be observed that, whatever be the nature of the intermediate machinery employed to transmit the power of the water, a portion of that power must always be lost: 1, because the whole velocity of the water cannot be destroyed, or else the water after producing its effect upon the machinery could not flow away; and 2, because the machine transmitting the power of the water, has a motion and a velocity proportionate to the latter, which consequently can only act by the excess of its velocity over that of the machine.

59. Water may act in several manners to produce motion, either by percussion, by pressure, or by re-action. It acts by percussion when it strikes the portions of any machine placed in its course, and when, after having communicated its movement to the machine, it flows away immediately after producing the shock; float wheels placed in a current are illustrations of this action. Water acts by simple pressure when, having no initial velocity, or one which is very small and only equal to that of the body on which it acts, it moves the latter merely by its weight; as in the case of bucket wheels, when the velocity of the periphery of the wheel is equal to that of the stream. Water acts both by percussion and by pressure, when it falls upon a bucket wheel with a velocity greater than that of the wheel itself. Lastly, water produces its effect by re-action in turbines, or in what are called for this very reason re-action mills. In the case of the hydraulic press the law by which a liquid enclosed in a

vessel on all sides is able to transmit, to every portion of its bounding surface, a pressure exercised on any point thereof, is called into action. As the details of the various machines by which the power of water is applied, and the laws connected with its application form part rather of the science of practical mechanical engineering, than of civil hydraulic engineering, the student is referred for them to the Numbers of Mr. Weale's Elementary Series, in which those subjects are particularly discussed.

PNEUMATICS.

60. Correctly speaking, the term Pneumatics ought to be confined to the science of the phenomena connected with the atmosphere; but, by extension, it has also been applied to those connected with all gaseous fluids. The following observations will, however, be confined as much as possible to the phenomena which would be represented by the narrower acceptation of the term, and those of other gaseous fluids will only be alluded to as they may be connected with the atmosphere itself.

61. As was already observed (§ 3.), gaseous fluids differ from aqueous fluids in this important respect: that the former are highly elastic, whilst the latter are so very partially elastic as to warrant the neglect of that property in all reasoning with respect to these fluids. Of the gases themselves, again, there are some which are permanently elastic, and others which, by means of compression, can be converted into liquids. Atmospheric air is an illustration of the compressible, steam of the incompressible, gases; but Faraday's beautiful researches lead to the belief that this distinction only exists in consequence of our defective means of operating upon them, and that, in reality, all

gases are susceptible of being compressed and condensed when operated upon under favourable conditions. In ordinary language, it is, however, convenient to retain the distinction between the condensible and the incondensible gases, and to apply to the former the name of the *permanent gases;* to the latter, that of *vapours.*

62. The properties common to all gases may be stated as follows: 1, that their elements have weight; 2, that they tend constantly to dilate, in consequence of the repulsive force of their latent caloric exceeding the molecular attraction, and that, therefore, they only retain the same volume from the resistance of some containing body; 3, that they are easily compressible on account of the space around their molecules; 4, that they are elastic, inasmuch as when their molecules are brought into closer connection with one another, the repulsive force of the caloric of the gases increases more rapidly than their molecular attraction; 5, that their molecules are perfectly free to move upon one another; and, 6, that, by reason of their elasticity, a force exercised upon them on one point must be transmitted throughout and in every direction. All these properties have been proved by direct experiment to be possessed by atmospheric air.

63. Since the atmosphere possesses weight, compressibility, elasticity, and the power of communicating pressure in every direction, it follows that any particular portion of it must be pressed by the weight of the atmosphere immediately above the portion under consideration, and must also transmit the effect of this weight to the portions beneath; consequently, the density of the atmosphere, and its elasticity, must decrease as the distance from the earth increases. For the same reasons, every object, or body, placed in the air must be exposed to a pressure upon every part

of its surface, which diminishes with the elevation above the ground.

64. The atmosphere revolves with the earth, and at the same velocity with it; for, if this were not the case, the air at rest would create a resistance to motion equal to the shock it would actually produce if the earth stood still. A current of air, in fact, would be felt, whose velocity would be equal to that of the earth's rotation on its own axis, or, at the circumference, to a velocity of 1518 feet per second; whilst the most violent hurricanes, such as are able to tear up trees and overthrow buildings, do not travel at a rate exceeding 147 feet per second. As the atmosphere thus moves with the earth, all the molecules composing the former are affected by three cosmic forces—gravity, elasticity, and the centrifugal force. Under these circumstances, as the weight and the elastic force of the molecules of the atmosphere diminish in proportion to the distance from the axis of rotation; whilst, on the contrary, the centrifugal force increases with that distance; there must necessarily exist upon any vertical line passing from the centre of the globe a point where these three forces are in equilibrium and the atmosphere must be limited. It has been calculated that the distance at which the atmosphere becomes rarefied to such a degree as to be 760 times lighter than it is at the ordinary level of the earth—a rarefaction equal to that obtained by the best air-pumps—is about 58,000 yards above that level. This is not more than $\frac{10}{1225}$ of the radius of the earth; so that practically it may be considered that the height of the atmosphere above our globe is about equal to $\frac{1}{100}$ of its radius.

65. If a tube be made air-tight, and filled with any liquid, so as effectually to exclude the air, and then

immersed in a vessel filled by some other liquid whose surface is exposed to the pressure of the atmosphere, it will be found that a column of the first liquid, or of that within the tube, will be sustained in it, and that the height of this column will depend upon the relative specific gravities of the liquids, and be in the inverse ratio of their densities. The force which sustains such a column is produced by the pressure of the atmosphere acting directly upon the exposed surface of the receiving vessel, and pressing it in a downward direction, whilst the liquid in the tube is exposed to no such action; and the effect will be the sâme, whatever be the section and dimensions of the tube, provided it be not so small as to allow capillary attraction to modify the results. Moreover, the pressure of the atmosphere may be demonstrated to act on every side of the tube or of the receiving vessel; for if the tube be made to assume any direction, the liquid will rise in it to the same height above the surface of the receiving vessel as it would do in a tube held in a perfectly vertical position.

66. As the heights of the liquid columns thus sustained in tubes are precisely in the inverse ratio of the densities of the column, their weights must be exactly equal. Under these circumstances, as it is known that the atmospheric pressure will sustain, on the average, a column of mercury 30 inches in height, it will also sustain a column of water about 34 feet high, since the specific gravity of mercury is 13·56. But as the pressure of the atmosphere varies within such limits as to allow the height of the mercurial column in a tube also to vary 3 inches in height, the height of the water column will also vary to a proportionate extent; that is to say, within a range of about 3 feet 5 inches. The atmosphere itself must exercise

an average pressure of 15 lbs. on the square inch, or the weight of a square vertical prism of atmosphere measuring 1 foot on every side is about 2160 lbs. In works upon Physics, especially in those published abroad, the elastic force of gases is estimated by their relation to the atmospheric pressure, or, as we have seen the latter to be 15 lbs. on the square inch, that quantity becomes the unit of comparison in all such calculations.

67. It is to the pressure of the atmosphere upon the exposed surface of a lower vessel that the ascent of water in a tube from which air has been exhausted is owing. The removal of a certain portion of the air in the tube causes that which remains to expand, its elasticity at the same time diminishes, and the liquid from the lower vessel will rise until the weight of the column thus sustained, and the remaining elasticity and weight of the internal air, shall balance the external pressure. It follows from this law, that, for the same dilatation of the air, the liquid will rise to a height which will be in the inverse ratio of its density.

68. It must be evident, from what has been said above, that the height of a liquid column of any description, in a closed tube, might be taken as the measure of the weight of the atmosphere. But, for the purposes of observation, it has been found to be more convenient to adopt mercury as the standard of comparison, because it admits of the column being made shorter than in the case of any other liquid, on account of its greater specific gravity, and also because it is not so much exposed to give off vapours (whose elasticity would, to a greater or less degree, falsify the indications of the column) as the majority of liquids are liable to do. Even mercury itself gives off vapour; but within the ordinary range of the thermometer in

temperate latitudes, its elasticity is so small that the action of this vapour may be neglected without inconvenience. In the arts, then, we find that almost invariably air-tight tubes in which columns of mercury are free to move according to the pressure of the atmosphere upon the surface of a small cup of mercury in which one of their extremities is immersed, are used to ascertain the pressure of the latter, and are known by the name of Barometers. Of late years the direct pressure of the atmosphere upon a thin metal disc, or diaphragm, covering an air-tight chamber, has been made to indicate the variations in the weight of the atmospheric column, in the elegant and ingenious instrument the Aneroid; and this instrument has been employed for all the purposes connected with engineering to which the barometer itself had previously been devoted, These purposes are for observations upon the weather, and occasionally for ascertaining comparative altitudes; and it is to be observed, that within the range of temperature prevailing in the temperate zones, the use of either the mercurial or the disc barometers may be a matter of indifference. In warm climates, however, the expansion of the disc renders the indications of the aneroid doubtful. As these subjects are more particularly discussed in the Numbers of this Series which treat of Pneumatics and of Mathematical Instruments, the student who might desire further information on the use of the barometer, is referred to them, or to the works cited at the end of this treatise.

69. It is a necessary consequence of that which has been previously stated, that when a gas is compressed, it diminishes in bulk; and as its elasticity increases with its density, it must sooner or later arrive at such a state of condensation that the elastic force of the gas

itself shall balance the pressure exercised; but the laws affecting the condensation and those affecting the elastic force are yet but little known. Practically, and especially in the case of atmospheric air, it may be considered that the pressure exercised by a gas against the sides of a vessel containing it, is increased in precisely the same proportion as the space which it formerly occupied has been diminished; or, in other words, the elastic force of the air, or of any gas, is proportional to its density. It must be observed, however, that a variation in the temperature will affect the elasticity of a gas; for an increase of temperature will give rise to an increase of elasticity without, or even in spite of, any variation in the density.

70. One consequence of the elasticity of gases is, that they exercise a pressure upon their containing vessels independent of any other mechanical or external force; and in this respect they differ from ordinary fluids. The energy of the pressure so exercised depends upon the difference between the elasticities of the contained and of the surrounding gases, independently of any pressure which may be applied to the former.

71. The principles of Pneumatics are applied in the practical operations of hydraulic engineering, in the construction and application of pumps and syphons; and it is therefore necessary to enter into some details of those engines. Pumps are of numerous descriptions, and every maker has his own peculiar fancies with respect to the execution of their parts; but the only really philosophical distinctions between the various kinds of pumps are those founded upon the application or the neglect of the atmospheric pressure; or, the infinite varieties of these machines may be classed under the simple divisions of the *suction* and the *forcing* pump.

72. The ordinary suction pump consists of a *vertical pipe* immersed in water at the lower end; of a *piston*, moving in an enlarged portion of this pipe, called the *cylinder* or *barrel;* and of *two clacks* or *valves*, one of which is seated upon the pipe, and the other upon the piston itself. If, in such a pump, of the construction usually adopted, we suppose the piston to be at the bottom of the cylinder, and nearly in contact with the lower valve, upon raising the former the valve upon the piston itself will be closed by the downward pressure of the atmosphere, and a partial vacuum will be formed under the piston. The air in the pipe and barrel of the pump will, therefore, be rarefied, and unable to press upon the surface of the fluid beneath it, with the same force that the atmosphere presses upon the water in the open vase; and the latter force being no longer balanced, a column of water will be raised in the pipe, whose height will depend upon the atmospheric pressure and the perfection of the vacuum which can be created under the piston. If, further, we suppose the water to rise to a certain height in the pipe, and that the piston then descend to the position it first occupied, the air between it and the water will escape through the valve, and the water will upon the next ascentional movement of the piston again rise in the pipe, until at last the piston actually plunges into it, and the water rising through the valve is retained upon it when it again rises. On this return up-stroke the water above the valve is raised by the piston to the overflow; a further vacuum is created beneath the piston, and an additional quantity of water from the containing vessel is made to enter the pipe by the atmospheric pressure.

73. The height to be given to such a lifting pipe as we have above described, depends nearly as much upon

the perfection of the vacuum created as upon the atmospheric pressure itself. Instead, then, of being able to raise water by means of suction pumps about 34 feet, as we should be entitled to expect theoretically, it is very rarely that suction pumps can be made to work at greater depths than from 16 to 28 feet; and in all such machines the chances of diminished effect increase with the dimensions of the pump itself. In practice, the usual working depth of a suction pump is made about 24 feet; and the diameters of the suction and ascending pipes are usually made from $\frac{1}{2}$ to $\frac{2}{3}$ of the pump-barrel itself. It is necessary, in order to secure the greatest results from these machines, that when the piston descends it should touch the lower clack, so as not to leave any space between the latter and the under side of the piston. The power to be applied to the handle must be in excess of the sum of the weights of the column of water above the piston, and of the column in the ascending pipe, and also be sufficient to overcome the friction of the various parts of the machinery.

74. The forcing pump may be either a species of *lifting* pump, when the column of water is raised directly upon the piston; or strictly a *forcing* pump, when the water is driven by the piston into an ascending pipe. It is usual, in ordinary cases, to combine the suction pump with both these varieties of the forcing pump, in order to make as much use as possible of the atmospheric pressure upon the surface of the water.

75. Evidently any kind of pump, in which the whole weight of a liquid column has to be set in motion at each stroke of the piston, must be so disadvantageous, that it cannot be a matter of surprise that the ordinary lifting pump should be rarely used; nor will it be worth while here to dwell further upon it, than to say,

that this description of engine is really nothing more than the suction pump already described, the upper tube of which has been prolonged. The forcing pump consists of a barrel and suction tube, separated by a clack, opening upwards only into the barrel. The piston, instead of carrying a second clack, is solid, and the clack is placed at the entrance of the ascending pipe, which usually branches off from the barrel in a horizontal direction for a short distance, and then ascends vertically. The motion of the second clack is from the barrel outwards.

76. The action of a pump of this description will be analogous to that of the suction pump until the water rises into the barrel, from the atmospheric pressure; because the piston will rarefy the air beneath it, and the unbalanced pressure upon the containing reservoir, will cause a column of water to rise in the tube. When, however, the water shall have entered the barrel, the piston, upon its next down stroke, will cause the water to force open the foot valve of the ascending pipe, and to rush into the ascending column. The pressure of the water in the latter must act upon its base with a weight proportionate to its height, and if then a motive force be employed in excess of this pressure, the water will continue to be lifted to a height proportional to the assumed motive power.

77. In those suction and forcing pumps, in which the water does not rest upon the piston, the effort necessary to raise the latter is only the weight which would be required to move a weight equal to that of the column of water raised by the suction. But in the act of descending, the piston compresses (to a slight extent) the water, and causes it to flow through the foot valve, and to rise in the ascending column; consequently it requires a power able to set in motion the

whole weight of the latter. There must be evidently a great advantage in equalising these actions, which it is always easy to do, when the total height to which it is required to raise the water does not exceed 56 feet, by merely placing the barrel in the middle of the lift, as the clear difference of level between the upper and lower extremities of the delivery pipes is called. Beyond this height it becomes necessary to adopt mechanical arrangements, in order to communicate greater power to the descending, than to the ascending, stroke of the piston; and it is in such cases that the application of steam power produces some of its most useful and startling results, as exemplified in the large mining, or water-supply engines.

The pistons of forcing pumps were formerly always made of wood, or of metal, packed with leather, so as to work closely against the sides of the barrel; but latterly, the so-called *plunger* pumps have been more generally used. In these pumps the *plunger* is a metallic cylinder, either solid or hollow, of a length a little greater than that of the stroke; the diameter being from $\frac{1}{2}$ to 1 inch less than the diameter of the barrel. The packing is fixed, and it is indeed formed by the stuffing-box. The plunger, in its descent, takes the place of the water, which it drives before it; and in its ascent it creates a vacuum in the suction pipe, which is immediately filled by the atmospheric pressure upon the water in the lower reservoir.

78. In any pump, therefore, the useful results would be represented by the formula $Pm = Wh$, in which we have

$Pm =$ the motive power employed;

$W =$ the weight of the water raised; and

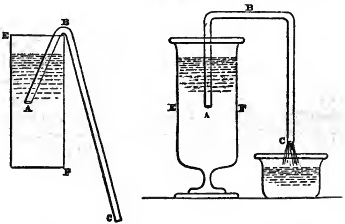
$h =$ the height to which it is so raised above the well.

Practically, however, the useful effect is diminished

by the friction of the packing, of the piston rod, and of the column of water against the sides of the pipe; there is also a loss of power occasioned by the mode of transmission of motion. Moreover, the weight and the friction of the clacks diminish the effective discharging power of the pump; as also must the variations in the direction and velocity of the ascending column, to which must be added, the influence of the velocity of the stream at the point of discharge. In the most perfect descriptions of pumps, it is possible that Wh may = from 0·75 to 0·80 Pm; but, generally speaking, the coefficient of the useful effect does not exceed, even if it attain so much as, 0·75.

79. Syphons are bent pipes, with legs which are, for the most part, of unequal length; and they are, in the arts, most frequently used for the purpose of transferring liquids from one vase to another, in such wise as to avoid any motion in the liquids of a nature to affect their mechanical purity. The simplest form of the syphon is represented by the annexed sketch

Fig. 8.



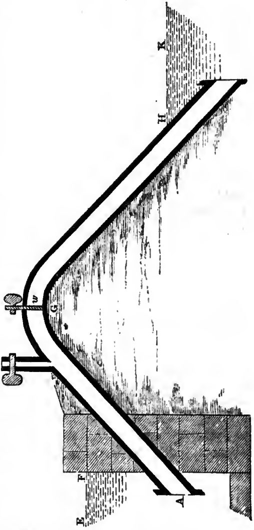
(fig. 8), and if, in such a machine, the bent pipe, A, B, C,

be filled with water, and the short leg, A B, be inserted in the vase, E F, the water will be discharged in a continuous stream through C, if the latter be opened, and the section of the bent tube should not be too great. The rapidity of the discharge will be increased in proportion to the increased difference of level between the surface of the fluid in E F, and that of the orifice of discharge; or it may become constant, or even cease altogether, when that distance is made to retain a fixed proportion. The theory of the movement of fluids in syphons is very simple; and the practical application of the principles upon which it was founded, as usual, preceded the clear recognition of the principles themselves; for the ancient Egyptians and the Romans appear to have habitually employed this class of machinery in the ordinary transactions of business, if we may judge by the pictorial representations which have been preserved. It was reserved however, to Pascal to discover the laws which affect the detailed action of syphons. It is to this author then that we owe the authorative announcement of the laws, briefly sketched in the following paragraphs.

80. As the pressure of the atmosphere on a water surface is able to support a column of about 33 or 34 feet high in a hollow tube, wherein a vacuum has been made in the upper part, if we suppose that a small partition *w* be placed in G, or the highest portion of the syphon (fig. 9), the column between G and E F will not only be sustained, but it will be pressed against the partition *w* with a force equal to the weight of a similar column, having a base, *w*, and a height of from 33 to 34 feet, minus the difference of level between the surface E F and the partition *w*. But when the syphon is filled with a fluid, the opposite side of the partition *w* is acted upon by a column of the same transverse

dimensions as before, having, however, the height of 33 or 34 feet, minus the difference of level between *w* and the surface, H K, of the lower or receiving vase; this pressure, consequently, is less than the first. It follows, therefore, that if the partition *w* were moveable, or, to return to the actual conditions of syphons, if there were no such partition, that the liquid section at the highest point would be urged in the direction A, G, H, by a force equal to the difference between the levels of the liquids in the upper or lower vessels thus put in communication with one another.

Fig. 9.



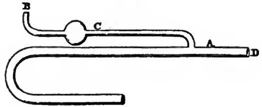
81. In the above reasoning it is supposed that the pressures exercised in the interior of the syphon upon the levels of the respective vessels are equal,

and of the same character; but this would not be so decidedly the case if the syphon and the vessels were immersed in a liquid able to exercise a pressure upon the exposed surfaces of the reservoirs, such as to counteract appreciably that of the column producing motion. Thus, for instance, if the vases were filled with mercury and immersed in water, the pressures upon their surfaces would be very different, and the excess of the first over the second would equal that produced by a column of water equal to the difference between the levels of those surfaces. This excess of pressure, which acts to raise the mercury in the longer leg of the syphon, would immediately retard the flow; and the pressure, which will really produce the movement of the liquid, would only be equal to the difference of the weights of two columns of mercury and water having the same bases and lengths, equal to those of the respective branches measured between the surfaces of the vessels. A very curious fact results from this law; namely, that if the liquid exterior to the syphon were denser than that in the interior, the direction of the flow would be reversed, or that it would take place from the longer to the shorter leg of the syphon. This phenomenon is rarely exhibited in the transmission of liquids; but it may be observed to take place in the movements of heated gases in chimneys, or in artificial ventilation.

82. In using syphons the ordinary course is to fill the instrument with the liquid to be transferred, either by pouring a sufficient quantity into the tube, or by exhausting the air in the longer leg, which leaves the pressure upon the surface of the upper vessel unbalanced; and therefore allows the liquid to rise over the summit of the syphon. The ordinary form of the syphons used in the arts, or for philosophical experiments, is that represented by fig. 10, in which a lateral

tube, C, B, A, is soldered to the side of the longer leg, and has a small bulb at the point C. When this

Fig. 10.



instrument is used, the extremity, D, is closed, and the air is exhausted from the interior, the exhaustion is known to be completed by the arrival of the liquid at D; if D be then opened, the liquid will continue to flow through it; but it must be observed, that inasmuch as the longer leg communicates with the air at C, the effective pressure is limited by the height of the latter. When large syphons are used, as in the case of waterworks, or embankments against the sea, it is necessary to have their two extremities immersed; for otherwise the air would enter and accumulate in the longer leg to such an extent as to cut off the column. To set these large syphons at work, it is usual to exhaust the air they may contain, and then to fill them by means of a small pump placed near their summits; when the liquid rises up to the pump itself, its clack is fastened down, the bottom valve of the syphon is opened, and the passage of the fluid commences. A very good description of the syphons used in the Don Reservoirs, by Mr. R. Mallett, will be found in Weale's "Quarterly Papers on Engineering, 1847;" and in Borgnis' "Traité des Machines, vol. 3, Paris, 1819," will be found some useful information upon the subjects of both pumps and syphons.

83. Several machines, whose actions depend upon

the application of the laws of pneumatics, are used occasionally in hydraulic engineering, such as the diving bell, camels, floating docks, &c.; but their details belong so much more especially to the other branches of practical mechanics, that it may suffice merely to allude to them at present, or to describe some of the more important of them incidentally in subsequent parts of this work. The application of the motive power of wind to land drainage is, however, often of so great importance, that it seems advisable to dwell upon it somewhat more in detail than it is proposed to do with respect to the class of machinery just mentioned.

84. Smeaton, in a paper communicated to the Royal Society 1757, drew up the following table of the velocity, and the perpendicular force of the wind under different circumstances.

TABLE IV.

Miles per Hour.	Feet per Second.	Perpendicular Force on One Square Foot in Avoirdupois Pounds and Parts.	
1	1·47	0 005	Hardly perceptible.
2	2·93	0·020	Just perceptible.
3	4·4	0·044	
4	5·87	0·079	Gently pleasant.
5	7·33	0·123	
10	14·67	0.492	Pleasant, brisk.
15	22·00	1·107	
20	29·34	1·968	Very brisk.
25	36 67	3·075	
30	44·01	4·429	High wind.
35	51·34	6·027	
40	58·68	7·873	Very high wind.
45	66·01	9·963	
50	73·35	12 300	Storm or tempest.
60	88·02	17·715	Great storm.
80	117·36	31·490	Hurricane.
100	146·7	49·200	Hurricane, tearing up trees and overthrowing buildings.

It has been found, practically, that a wind moving with a velocity of less than ten miles per hour is not

able to insure the working of a corn mill; when the velocity exceeds twenty miles per hour it is necessary to furl the sails. A wind travelling with the last-named velocity is, however, considered to be the most suitable for the purposes of navigation.

85. According to Smeaton also, a windmill yields the greatest effect when its sails are made with concave surfaces of a rather complex form, the generating lines of which, situated at points obtained by dividing the length of the sail into six equal parts, form with the axis of the shaft, or the direction of the plane of movement of the sails, the angles indicated in the following table. (The generating line No. 1 is that which is nearest to the axis, and it is at this point that the sail begins.) Usually the width of the sail varies between $\frac{1}{5}$ and $\frac{1}{6}$ of the length; and, in the best mills it never exceeds $\frac{1}{4}$ of that dimension.

TABLE V.

No. of generating Line.	Angle with Axis.	Angle with Plane of Movement of the Sails.	Observations.
1	72°00	18°00	The angles of the third column are the complements of those in the second.
2	71·00	19·00	
3 middle	72·00	18·00	
4	74·00	16·00	
5	77·50	12·50	
6	83·00	7·00	

86. From the same authority it would appear that when the sails of a mill are well filled, the velocity of their extremities, without a load, is equal to four times the velocity of the wind; and that it is necessary that the velocity of the extremities, with a load, should be

2·5 or 2·7 the velocity of the wind, in order to obtain the maximum useful effect. These same useful effects produced, are found to be in the ratio of the cubes of the velocity of the wind, and they may be represented by the formula $P = \frac{v^2 a^2 sin^2 \theta}{440}$, in which P represents the impulse in pounds avoirdupois; v, the velocity of the wind in feet per second; a^2, the area of the sail in feet; and θ, the angle to the direction of the current. Claudel gives a very simple and a very useful formula for estimating the power exerted upon a plane surface, normal to the direction of the movement of the wind, which may be usefully quoted here; it is the one in which

$$P = ds \times 2h, \text{ wherein}$$

P represents the pressure in lbs. per foot superficial; d, the weight of a foot cube of the air in movement; s, the surface of the plane receiving the shock, measured in feet superficial; and h, the height producing the velocity, or $h = \frac{v^2}{2g}$ according to the usual formula upon the subject. In this case it is supposed that the barometric pressure is equal to 30 inches of the mercurial column, and that the temperature is equal to 53·6; under which conditions d would equal 2·71 lbs. avoirdupois.

87. In Holland windmills are extensively used for the purposes of drainage; and it is the practice in that country to employ one mill, with sweeps of from 80 to 90 feet in diameter, for every 1250 acres drained, provided the lift do not exceed 5 feet. These mills are considered to work upon the average 60 days in the year, and to raise an effective total quantity of water equivalent to 695,220,000 cubic feet of water lifted 1 foot vertical. But it must be observed that the

Dutch "Windwatermoelen" are very far indeed from yielding the maximum working effect they might produce if they were built upon the more modern and certainly more approved plans. It is extremely rare to see a mill which "winds" itself; and still more rare is it to see the sails of a mill provided with self-regulating wooden blades, instead of canvas sails, which must be furled by hand or be blown to rags if an unexpected storm should arise. In England it has been found to be, on the whole, more economical to employ steam power than to use the motive power of the wind for the purposes of drainage, as we shall have occasion hereafter to mention in the chapter of this work, especially devoted to the consideration of this question. Where coal is dear, and iron is expensive, windmills will always be of the greatest value for engineering purposes; and it is, therefore, much to be regretted that this class of engines should have been so systematically neglected as it has been of late years, especially by English engineers.

88. Coulomb observed, we may here add, that the total annual work of a windmill was only $\frac{1}{3}$ of the effective power which such a machine would be able to produce by working continuously under the most favourable circumstances. This calculation is very far in excess of those of the Dutch water engineers; and the experiments of both Hachette and d'Aubuisson, show that Coulomb was certainly deceived in the matter. It is but fair to observe that the class of water raising machinery, to which the Dutch windmills are generally applied, is of the rudest and most incomplete description of "dash wheel," as it is called; and that really, in any machine of this particular description, the simplicity of its construction and the facility of its repairs are often of much greater importance than the

attainment of the maximum dynamical effect from the motive power employed.

89. There are many other phenomena connected with the science of pneumatics of great interest to the engineer and to the public in general; such as those connected with the movement of gases in pipes, aërostation, sound and its transmission, evaporation, distillation, crystallisation, &c.; to some of which it will be necessary to refer hereafter in the consideration of the practical details of the comprehensive science of hydraulic engineering. In the meantime, if the reader should require, at once, further information upon the numerous subjects thus alluded to, he is referred to the other Treatises in this series, especially to those upon hydraulics, pneumatics, rivers, &c., and to the list of authors to be found in the Appendix to the present work.

APPLIED CHEMISTRY.

90. The conditions under which the various building materials decay have so great an influence upon the stability of the structures erected by the hydraulic engineer, that their investigation ought always to command attention. There is much obscurity, however, with respect to the practical application of the great principles of chemical science to building purposes; and the various actions and reactions produced by the materials used, or by the external agent to which they are exposed, have not yet been studied in any consecutive or philosophical spirit. The following remarks must, therefore, be considered rather as an attempt to collect and record the little which is actually known upon the subject, than as a statement of a body of scientific principles. It would perhaps be convenient for the purposes of investigation to discuss the

condition of the chemical actions observable in building materials, 1, in air, and 2, in water; but these actions are often so intermingled that any such subclassification can only be partially observed.

91. Of course all these materials are perceptibly affected by the changes of volume produced by variations of temperature, and in designing any important building of the class now under consideration it is absolutely necessary to take into account the probable effect of the dilation consequent upon an increase of that description. Extreme cold, however, exercises a more marked influence upon the mechanical structure of building materials than the ordinary degrees of heat are able to do; and this influence is itself the greater in proportion to the amount of water which may be present in the pores of the material. It is indeed principally on account of the change of volume produced by the passage of the contained water from the liquid to the solid state during congelation, that disintegration ensues; and it therefore follows, that up to a certain point, and under certain conditions, the facility with which any substance absorbs water may be considered to be an indication of its tendency to decay under the influence of extreme cold. There appear, however, to be several very marked exceptions to this rule, at present inexplicable; for some of the more commonly used descriptions of building stone absorb water freely, but do not yield easily to the effect of cold; and in the case of the distinctly marked bedding of the Yorkshire paving, it rarely happens that the water which may exist between the layers causes these to separate upon the occurrence of frost. The various metals are often seriously affected by extreme cold, and this influence extends not only to their change of volume, but also to the modifications of their other

physical characteristics; for instance, some of the metals become in times of frost extremely brittle, or they lose in fact much of their malleability. Iron is especially liable to this action, cast iron even more so than wrought; and it would appear that there is some kind of inverse relation, hitherto not clearly ascertained, between the rates of fusion of the different metals, and their susceptibility of change in their conditions of malleability under the action of extreme cold. Woods vary less in volume with changes in the atmospheric temperature than the other building materials, especially when they have previously lost their sap; but even they are not exempt from the action in question, and it has been observed that a species of torsion of the fibres takes place in wood when directly exposed to the sun's rays, and that the fibres slowly and imperfectly follow their path. The influence of frost upon the cohesion of building materials becomes of the most serious importance in cases wherein machinery of any description is employed; and it is therefore impossible for the hydraulic engineer to exaggerate its importance. The rupture of chain cables, tie-rods, bollards, &c., when exposed to sudden shocks during hard winters, is of sufficiently frequent recurrence to justify the short notice thus given of its danger.

92. The chemical actions which take place in building materials are, however, even more injurious than the very decidedly mechanical ones thus alluded to; but they are similarly affected by the conditions of temperature; and as they depend upon the reciprocal influences of the atmosphere, and of the elementary substances of the materials in question, it may be desirable, first, to notice in general terms the composition of the atmosphere, and then to examine briefly the changes it is able to produce: the composition and

action of sea water will be noticed incidentally. In its normal state, the atmosphere is considered to be composed of oxygen and nitrogen, in the proportions of 208 of the former to 792 of the latter; but it also contains, in variable proportions, dependent upon local causes, numerous other gases, such as carbonic acid, ammoniacal, hydrochloric, nitrous, sulphurous, and sulphuretted hydrogen gases; and it is important to observe, that the relative proportion of these gases varies in the same locality with the elevation above the ground. Messrs. Boussingault and Lévy ascertained that the quantity of carbonic acid gas present in the atmosphere of Paris was 3·253 parts in 10,000, whilst at Andilly it was only 2·989; but Lévy himself considers the proportion of this gas usually to vary between the limits of from 4 to 6 parts in 10,000. Carburetted hydrogen is found most abundantly in the neighbourhood of marshes; nitrous acid gas in districts which are subject to violent storms. Frésenius states that the quantity of ammonia (in various forms, such as the oxide and carbonate) usually to be found in the air, is about 0·677 in 100,000; a quantity Boussingault's observations would lead us to believe to be less than the one which really obtains, for he found that the ammonia in rain water varied from 1 to 5·45 in 100,000, and that the proportion depended mainly upon the position of the place where the water was collected. Under any circumstances, it appears that the night air contains more ammonia than than that of the day; that of towns contains more than the air of country districts; and from the observations of M. Chevalier, it would appear that other forms of ammonia (the acetate and hydrosulphate) are often to be discovered in notable proportions in the air of towns. Vogel ascertained that the air of the shores of the

Mediterranean and of the Baltic contained a certain proportion of hydrochloric acid; and there seems to be every reason to believe that the same fact must exist in other localities of the same description, dependent of course upon the rate and conditions of evaporation there prevailing. Many other gases must, no doubt, be present in the atmosphere, though from their extremely minute proportions, it is difficult to ascertain their precise influence, or even their existence, in some cases.

93. The meteorological conditions of the atmosphere are subject to periodical variations, and they have distinctly marked phases of nocturnal and diurnal energy, unless any extraordinary circumstances should occur to modify their action. Thus, in clear weather the atmosphere attains two maxima and minima in its electrical state; the first maximum occurring between seven and nine in the morning, and the second between seven and nine in the evening; the first minimum about four in the morning, and the second between five and ten in the evening: but it must be observed that the hygrometric state of the atmosphere frequently modifies the above cited periods. The intensity of the sun's light, and, therefore, necessarily that of its actinic influence, has its maximum rather before midday, and it has two minima corresponding nearly with twilight. A maximum occurs in the temperature about two o'clock in the afternoon, on the average of the year, but there is a slight irregularity according to the seasons; a minimum occurs, according to M. Bouvard's observations carried on in Paris, when the sun, in the early part of the day, occupies a position of about $14° 17'$ below the horizon; the period of the diurnal mean temperature varies in the different months of the year. It is about midday that the atmosphere is generally in

its driest state, and about midnight it contains the greatest quantity of moisture; whilst it is between midnight and sun-rise that the greatest deposition of dew takes place, on account of the greater degree of cold we have already seen to prevail about that part of the day. In our particular (northern) localities the disturbances of the barometric action are not characterised by any regularity; but, as a general rule, there appears to be a tendency in the atmosphere to increase in pressure in the morning, for the mercury in the barometer then generally rises; it falls about midday; rises again about sunset; and falls once more about midnight. In fact, however, it may be considered that the fluctuations in the meteorological conditions of the atmosphere are affected by the relative positions of the sun and of the earth; and that they rudely correspond with the cardinal positions of the former of those bodies, at its so-called rising and setting, and at midday and midnight. In London itself, the mean temperature throughout the year is 50° 50′, whilst that of the adjacent country districts is 48° 50′. The thermometer in that town very rarely rises about 96°, and the greatest cold recorded has never descended below 5° under zero of Fahrenheit's scale. The mean range of the barometric pressure does not exceed 2·07 inches.

94. One of the most important conditions of the atmospheric action upon building materials is that one connected with the rate of evaporation, and the amount of humidity in suspension; and the intensity of these respective phases of the hygrometric influence is the greatest at precisely opposite seasons of the year. That is to say: evaporation is the most active in the summer, and the least active in the winter months; whilst the opposite law prevails with respect to the

amount of moisture in suspension in the atmosphere. Thus, Mr. Daniel estimated the total mean evaporation in the neighbourhood of London at 23·974 inches per annum, ranging in the various months of the year from about half an inch in January and December, to $3\frac{3}{4}$ inches in June, and $3\frac{1}{4}$ inches in July; and, assuming the complete saturation of the atmosphere with humidity to be represented by 100, that of the months of December, January, and February will be expressed by 92. In the intervening months the humidity diminishes with tolerable regularity to a minimum of 78 at the end of June, excepting that a trifling irregularity occurs in the month of May. It thence appears that the greatest amount of moisture is suspended in the atmosphere precisely at the period when the temperature is the lowest, and when frost is the most likely to affect the moisture which might be absorbed by the porous building materials; whilst, on the other hand, evaporation takes place with the greatest energy at the period when the conditions of temperature would be most favourable to the production and development of the salts generated by the action of the absorbed moisture upon the earthy bases of those materials, which salts are either themselves actively destructive, or from the fact of their solubility or of their deliquescence, facilitate the decomposition of the various metals, stores, or timbers.

95. The conditions under which mineral substances have crystallised appear to exercise a great and hitherto unexplained influence upon their powers of resistance to external agents; and it would also appear that it is a matter of great importance to have the original crystallisation undisturbed. Thus, in the cases of the various descriptions of silica usually dealt with by the hydraulic engineer, we find that the

decidedly characterised form of the "quartz" is able to resist any ordinary amounts of heat and nearly all chemical actions, but that flint, an imperfectly or amorphously formed crystallisation of silica, is susceptible of decomposition in caustic alkalis under high pressure; and that the silica beds of the subcretaceous group can be reduced with comparative ease to the gelatinous form without pressure. Again, the amorphous limestones, such as the common chalk, are soluble in water with comparative ease; but the more decidedly crystallised oolites, or any of the more dense and more regularly formed stones or marbles, resist the solvent action of that element in a very marked manner. But all forms of crystallisation are not thus permanent, and there is, for instance, a large class of materials used in building—the sulphates of lime—which slowly dissolve under the action even of the moisture in suspension in the atmosphere. Any mechanical interference with the crystals of the various bodies under consideration has a decided influence upon their durability, not only because it destroys the coherence of the mass, but because it leaves the separate molecules more exposed to the attacks of external agents. It is for these reasons that it is undesirable to attempt to alter the forms of metals after they have once crystallised in cooling; nor can the practical results obtained by the lamination of iron, lead, or zinc be considered to invalidate this opinion; because, first, those metals possess rather more of a fibrous than of a distinctly crystalline character, and secondly, there is reason to believe that a fresh arrangement of the crystals actually takes place under the influence of the various actions developed during, or by the composition. In the case of the cast, and subsequently rolled glasses, the effects of

the subsequent interferences above alluded to may often be distinctly observed.

96. The hydraulic engineer, however, is most directly interested in the study of the influence of the laws of crystallisation upon the resistance of such materials as bricks, and limes and cements, which enter so largely into the constructions he is employed to direct. It would appear, in these cases, that the durability of the silicates, whether simple or compound, depends mainly upon the facts of their gradual formation, if obtained solely in the humid way, or of their formation under the influence of intense heat, if obtained by any rapid process. It is for this reason that the powers of bricks to resist decay depend mainly upon the degree of burning to which they have been exposed. Of course this degree must vary with the composition of the clay of which the bricks are made, and it would be the least in those clays containing bases able easily to form crystalline double silicates in combination with the alumina; but it is notorious, that the underburnt pulverulent bricks, or those in which no indications of a rude crystallisation can be observed, rapidly decay in damp positions, although even there they may serve one good purpose, to be noticed hereafter; whilst the dense, semi-vitreous, and crystalline texture of the harder burnt bricks enables them to resist external agencies. In the phenomena connected with the solidification of some limes the facts above mentioned are perhaps even more distinctly observable; for it is now established with tolerable certainty, that limes and cements only resist the dissolving action of sea-water when they have previously given rise to the formation of a subcrystalline double silicate of lime and alumina, or of lime and magnesia. This double silicate is formed slowly in cases wherein

the lime is obtained from the argillaceous limestones containing small doses of alumina, more rapidly in those wherein the clay exists in larger proportions in the stone; but in neither of these cases do the resulting cementitious materials attain the ultimate hardness or powers of resistance which they do when obtained from a mixture of the proper proportions of chalk and clay (carbonate of lime and silicate of alumina) burnt at so high a temperature as to produce the commencement of vitrification. It is upon this principle that the Portland cement may be considered to be so much superior to other materials of the same description; and it is upon the principle of the slow formation of the silicate of lime and alumina in the humid way, that we may explain the useful action of the soft bricks alluded to above. The alumina is, in fact, gradually taken up by the lime, or a portion of the lime passes into combination with the alumina of the bricks, by a species of interchange when such materials are constantly exposed to water; in workmen's phrase, they thus become "water bound." But alike whether the combination take place slowly or rapidly, whether it take place in the dry or in the humid way, neither the simple nor the double silicates can be resistant to external meteorological agents unless they have assumed a commencement of crystallisation, and the more perfectly that action has taken place the more permanent will be the resulting substance.

97. Of the natural building materials, so to speak, usually employed, a very large and important class—viz., those containing much felspar, such as the plutonic rocks, or the granites, porphyries, whinstones, or basalts—yield to the ordinary action of the atmosphere in variable degrees, according to the composition of the felspar itself and to the conditions of their

crystalline arrangement. It may be that the greater compactness of some of these materials influences their resistance, and that their homogeneity, or their mixed structure, may likewise have some effect; for, evidently, the more open-grained or porous materials must absorb greater quantities of water than the denser ones, and they must, consequently, be more likely to be affected by the changes of form of the water itself: and it must equally be evident that the different rates of expansion of the elementary substances which enter into the composition of the various compound bodies must tend to disintegrate the latter, if those rates be allowed to operate in their most extreme degrees. The decay of these materials, then, may be considered to be as much mechanical as it is chemical; and a safe rule may be established as to their use, namely, that those should be preferred which, *sui generis*, have the smallest grain, the most regular crystallisation, and the simplest composition; the mere specific gravity of the plutonic materials is in itself nearly an infallible criterion of their powers of resistance to meteorological agencies. The same remarks may be extended to the slate rocks, for their durability mainly depends upon their density and the even texture of their mass.

98. In the sandstones and conglomerates, decay may proceed from either the decomposition of the cementing materials, or from the mechanical disintegration resulting from the unequal contractions produced by changes in the state or temperature of the atmosphere. If, for instance, the cementing material should be a limestone, or even a clay, it may often be soluble in water frequently renewed, especially when that water contains any appreciable proportion of carbonic acid gas, as is almost always the case in rain water. Or again, if the cementitious material should be simply of a different

capacity for heat to that of the substances united, or if they should principally be disposed in layers between the principal ingredients of the mass; frost will be very likely to cause them to disintegrate. It is thus that stones, such as the Bramley Fall, in which the cementitious material to the large grains of silica is itself nearly a pure silica, resist external causes of decay with remarkable energy. Whilst, on the other hand, some of the Yorkshire stones, those in which the layers of agglutinated sand are occasionally separated by means of thin sheets of clay, are markedly exposed to decay from the fact of the filtration of water between the various beds. It is, however, important to observe, that the decay which actually arises with these materials does not affect the silica, or their main element, so much as it does the cementing material, or the adventitious substances entering into their composition. With limestones, however, this ceases to be true, for both the carbonates of lime (whether argillaceous or not) and the magnesian limestones, are more or less easily soluble in pure water, or in water containing small doses of carbonic acid. It may, therefore, be considered that the hydraulic engineer should avoid, as far as possible, the use of building materials of this description under water; and if from local considerations of economy he should not be able to use the siliceous stones of a dense, uniform, and crystalline nature, he must be careful in selecting such limestones as are likely, from the conditions of their structure, to resist the action of the element to which they are exposed, or, in other words, to select the densest, most uniform, and most crystalline varieties of limestone.

99. When permeable building materials are exposed to alternations of wetness and dryness, or are used

upon the limits of their capillary action on the moisture of the ground, a chemical effect of a more complicated nature than either of those hitherto considered begins to take place. In proportion to the permeability of these materials themselves new salts are formed, by the decomposition of the original elements under the influence of the water, and of the gases which permeate their various substances. Not only does this action cause the bodies exposed to it to decay, on account of the chemical changes it superinduces, but the efflorescence of the salts thus formed tends to destroy the substances in which they are formed by the mechanical force developed in the process of their crystallisation. The generally received opinion on the subject of the formation of these salts is that they consist of the nitrate of soda—the saltpetre of commerce—or of the nitrate of lime, and that the nitrogen is furnished by the decomposition of the animal matter which is diffused through all stratified deposits. Dumas states that azote and oxygen combine most readily under the influence of electricity; but that the energetic bases, such as lime and magnesia, may suffice, especially when water is present, to replace that intermediate agent. However the formation of saltpetre upon building stones be explained, it is certain that it is produced in the greatest abundance in the zone of the alternations of dryness and humidity; and it may be observed that building materials decay, from this cause, much more rapidly when they are exposed to the action of tides, or at a small height from the ground, than they do under water, or immediately in contact with damp earth. It is, therefore, necessary to use, in positions exposed to the alternations above referred to, only such materials as are of a dense, uniform character, and are composed of elements

insoluble in water. Ordinary carbonates and magnesian carbonates of lime should not be used in these positions; but wherever it is possible so to do, the crystalline, or conglomerate, silica rocks should be employed, for they resist the chemical actions of gases quite as effectually as they resist the solvent action of water.

100. Wood when employed in works connected with hydraulic engineering is exposed to several special causes of decay, arising from the peculiar series of changes which take place in its elements under the influence of the organic substances it contains. The decomposition and fermentation of the sap, and the apparently spontaneous development of fungoid bodies, are amongst the most striking illustrations of these changes; but in addition to them, wood is of course exposed to the ordinary laws of inert chemistry, so to speak. The danger arising from the first cited causes of decay may almost entirely be obviated by observing the simple precaution of not placing the wood in a building until the whole of the sap has been withdrawn, and of maintaining something like a circulation of air round the portions buried in walls, if some portions should be thus buried, and others exposed to the air; for it is to be observed that woods which are constantly covered, either by earth or by water, do not decay in the same manner as those which are partially exposed. It is impossible at present to explain the reasons for the different resistances of woods, even under precisely similar circumstances; but it is essential for the hydraulic engineer to observe that such woods as oak and fir resist more effectually alternations of wet and dry, or, to use the workman's phrase, "last better between wind and water," than beech, ash, or elm; but that elm lasts for a very long time if kept constantly under water, and that beech

piles are even more durable than fir ones in damp ground, when the air can have no access to them. In either of the cases thus named there is no reason to fear the kind of decay resulting from the fermentation of the sap; for this action appears to require the presence of warm damp air, rather than the existence of constant moisture; and it is for this reason that freshly cut timber may be used in pile foundations which are not exposed to changes in their conditions of humidity, whilst it is indispensable to employ in the open air, or in exposed positions, properly seasoned wood, free from sap. When wood is only exposed to ordinary atmospheric changes, its preservation may, to a great extent, be secured by filling in the pores of the exposed surface with paint, or any other material of a nature to prevent moisture from penetrating to the interior; but it is essential, even in such cases, that the sap should be entirely removed before the external pores are closed, or the subsequent fermentation which will take place in it, will produce a peculiar decomposition of the woody fibre known amongst practical builders by the term, "wet rot." The "dry rot" is a species of fungoid growth, considered to be extremely destructive to wood; but perhaps it would be more philosophical to say that the fungoid growth in question developes itself in the most distinct manner under the circumstances which are most injurious to wood, that is to say, in confined, stagnant, warm, damp air.

101. Metals when exposed to the atmosphere are liable to decay, not only on account of the new compounds they form with the gases therein present, but also on account of the electro-chemical changes they undergo. As the number of metals used in ordinary building operations is confined practically to a very few, such as iron, lead, copper, tin, zinc, and the mixed

metals brass, or bronze, it may suffice to notice briefly the phenomena to which their exposure gives rise under ordinary circumstances.

a. Iron decays, or rusts, by the formation of a hydrous oxide of that metal, which is soluble in water frequently renewed, or which detaches itself in scales in the open air. When carbonic acid gas is present, the decay takes place with great rapidity, and it is even considered by some authorities that the presence of that gas is absolutely necessary for its development. Reasoning upon this supposition, M. Vicat and the French engineers adopted the system of surrounding the iron work they were obliged to bed in masonry with a hydrate of rich lime, believing that the latter would, on account of its great affinity for carbonic acid, prevent that gas from acting upon the iron. To a certain extent this reasoning is correct, but it is impracticable to keep the hydrate of lime in such immediate contact with the iron as to prevent the passage of moisture between the two substances, and the sad failure of the Suspension Bridge at Angers, in consequence of the rusting of the cables supposed to have been protected by their immersion in the hydrate of lime, may be referred to as an illustration of the danger of the system. It is usually considered that waters containing in solution small quantities of earthy salts act less injuriously upon iron than purer waters would do; and M. Payen ascertained, by direct experiment, that the addition of very small quantities of the sub-carbonate of potassa or of sodium to pure water, rendered the latter innocuous to either cast or wrought iron, and that the same preservative effect was to be observed in all alkaline solutions. On the contrary, however, he found that the addition of a small quantity of the chloride of sodium accelerated the ordinary

rate of oxidation. It appears that grey cast iron is more susceptible of rusting than either wrought iron, or white cast iron; and that the wrought metal resists the action of sea water better than the cast. When iron is exposed to frequent shocks, or vibratory movements, it is less affected by rust than when it remains constantly in one place without such disturbance; but the positions in which iron decays the most rapidly are those where it is fixed, and is alternately exposed to the air, or immersed in sea water. Ammoniacal and sulphuric acid gases exercise very serious effects upon the durability of iron.

b. Zinc when exposed to the atmosphere in its ordinary state rapidly combines with the carbonic acid contained therein, and gives rise to a whitish efflorescence adhering to the material and constituting, as it were, a protective varnish. When, however, any sulphuric or hydrochloric acid is present, as on the sea shore, or in towns like London, where much coal is burnt, various other compounds of a soluble nature are formed. In sea water naturally these compounds are formed more rapidly than in the air.

c. Copper resists external destructive agencies in a very remarkable manner; and many of the gases above enumerated, which are so injurious to other substances, are without effect upon it. Upon exposure to the air a film of either the oxide or the carbonate of copper is formed over the surface of the metal, and it effectually protects the latter against subsequent attack. Formerly copper was likewise considered to be able to resist the action of sea water better than any other metal could do; but of late years it has been asserted that a mixed metal, or species of bronze made of copper and zinc, resisted both the atmosphere and sea water more successfully than pure copper alone.

d. Lead undergoes little change upon exposure either to air or water, especially when the latter contains any of the salts of lime. Brande, however, makes the very important observation, that when lead is kept in distilled water to which air has access, small crystalline scales of the oxide of lead are formed, a portion of which dissolves in the water and is again slowly precipitated in the form of a carbonate. As the very pure, soft waters are nearly analogous to distilled water in their chemical composition, the same actions must take place with them; and it is notorious that they produce very distinct effects upon the lead to which they have access. The use of lead for cisterns must, therefore, be regulated by the nature of the water to be preserved in them; but there does not appear to be any reason why lead should not be applied in every district for ordinary purposes of construction.

102. A very curious, and a highly important, effect is observed to take place when two metals are placed in contact with one another, and when moisture has access to them. A species of galvanic action takes place, which causes one, or sometimes both of the metals to decay with great rapidity; and this may be observed to be the case whether the moisture contain carbonic acid or not, although it is most perceptible when that gas is present. Thus the feet of iron railings when run with lead into stone, or iron cramps, tie-rods, sockets, &c., run with lead into the masonry of locks or other hydraulic works, decay very rapidly, and the more so, in proportion to the purity and the malleability of the iron itself. A similar phenomenon may be observed to take place when iron is in contact with bronze, or with copper, in sea water; but, in this case, although the iron decays rapidly, it would appear to exercise a preservative influence upon the copper.

The preservative electrical action thus developed is not by any means confined to iron and copper, but it would appear generally to take place when two metals are in contact, and are immersed in a solution of any alkaline salts. Thus it is that zinc, tin, and iron, protect copper in sea water; that zinc protects iron and tin, but is itself rapidly corroded if used in sea water in contact with iron; that tinned iron decays unequally in that element, the iron oxidating rapidly, whilst the tin remains intact; and, indeed, the destruction of iron seems to take place more rapidly when that metal is in contact with tin than when it is in contact with copper. When waters contain much of the bicarbonate of lime, that substance is often deposited upon the soldered joints of the pipes through which it may pass, in consequence of a decomposition produced by the galvanic action of the metal of the pipes, and of the joints. It will be necessary to revert to this subject hereafter, in the portion of this work devoted to the consideration of the distribution of water to towns.

103. Mr. Robert Mallet has made many valuable experiments for the purpose of discovering some method for preserving iron from rusting, which have been recorded in the "Transactions" of the British Association for the Advancement of Science. From these experiments, it would appear that a coating of gas tar, applied hot, is the most efficacious protection to iron-work exposed to cold water, and that a coating of caoutchouc varnish is preferable when the iron is exposed to hot water; but that neither of them can be considered to be a durable defence. The process of coating iron with zinc, or galvanising it, is considered by some persons to be the surest mode of protecting the former metal; if, however, the protecting coat should be chipped or scaled off, the decay of the portions thus

exposed would take place with even greater rapidity than it would have done if no attempt had been made to guard against the danger; because, really, a galvanic action then "sets up," and facilitates the oxidation of the iron. So long, in fact, as the iron is covered it is in an electro-negative state, and it is known that during the existence of this state there is little tendency on the part of the iron to combine with oxygen; but this ceases to be the case when the iron is uncovered, for it is then free to assume any electrical state which may be superinduced by the atmospheric or other conditions around it, and then to decay as usual.

104. In the preceding remarks no particular attention has been directed to the composition of sea water, but the chemical actions it produces are sufficiently important to justify a cursory allusion to the subject, and at the same time to justify the reference of the student to the authors who have treated the subject in greater detail than would be consistent with the limits of this treatise. Sea water, then, has a specific gravity of 1·026 or of 1·028; and its freezing point is usually about 28·5°. Formerly it was considered that its composition did not vary much, from whatever latitude or longitude it was obtained, provided only that the depth from which the sample was taken was sufficiently great to ensure exemption from local disturbing causes; but the researches of Drs. Marcet, Daubeny, of Lenz, and of the French engineers, would appear to prove that notable differences may be found in sea water. Thus, Daubeny states, that the quantity of bromine present will vary at times from 0·915 grain in 1 gallon to 1·7 grains; Dr. Marcet says that the Southern Ocean contains more saline matter than the Northern, in the ratio of 1·02919 to 1·02757; and Daubeny states, in conformity with Lenz, that the

Atlantic is salter than the South Sea, and that the Indian Ocean is salter on the west than it is on the east. It would also appear that there exists a maximum of saltness towards the north, and towards the south, of the equator in all the oceans. Engineering operations are, however, seldom carried on in mid ocean, and it is to be observed, that the differences in the composition of the waters near the shores depend more upon local or accidental circumstances than they do upon any general law. Thus, the intermixture of fresh and salt water produced by the discharge of a river into a bay, the local rate of evaporation, and even the character of the impurities the fresh waters are likely to bring down with them, will materially affect the destructive action of the sea upon building materials.

105. It is usually considered that sea water retards the setting of limes and cements, by reason of the chloride of sodium and the other saline matters it contains; and if this be correct, the following table will be of interest; it contains the saline contents in 1000 parts of sea water (as given by Mallet, "Transactions" B. A., 1840, p. 223):—

Arctic Sea	28·30	Marcet
North Atlantic . . .	42·60	"
Equator	39·20	"
South Atlantic . . .	41·20	"
Mediterranean . . .	39·40	Laurent
Sea of Marmora . .	42·00	Marcet
Black Sea	21·60	"
Baltic	6·60	"
Dead Sea	385·00	"
British Channel . . .	35·50	Sweitzer
Irish Sea	33·76	Mallet

But perhaps the most destructive agent, so far as the instable combinations of lime and silica are concerned, is the magnesia present in sea water; and this varies but little in any ports hitherto observed. There are, however, very marked differences in the quantities of carbonic acid or of the hydrosulphuric acids to be discovered in the waters near large towns especially; and as they also are very powerful in their destructive actions upon the materials exposed to them, it becomes essential to examine carefully the nature and composition of sea waters before exposing new and untried materials to them. A great deal of useful information on these subjects is to be found in the various papers lately published by Messrs. Vicat, Minard, Chatoney, Noel, &c., in the "Annales des Mines et des Ponts et Chaussées," subsequent to 1856; in the "Proceedings" of the Royal Institute of British Architects, and of the Institution of Civil Engineers. Mr. Mallet's papers in the "Transactions" of the British Association for 1838 and 1840 are the most practically useful of any hitherto published as to the action of sea water on iron or on mixed metals, with respect to which, also, the publications of the Royal Society and the various technical journals may likewise be consulted. The most important results hitherto ascertained being that in the composition of mortars and cements for hydraulic works in sea water, there should be present a proportion of free lime, depending upon the carbonic acid or the sulphuretted hydrogen present in the sea; and that the contact of dissimilar metals, the scantling of a piece of cast or wrought iron, the contact of cast iron with wrought iron or steel, or even of one cast iron with another, may materially affect the rates of decomposition of the respective ingredients when immersed either in sea water or in what are

technically known as the bad waters of mines. There is, unfortunately, still a great amount of uncertainty upon the whole of this branch of applied science, to some of whose details we shall have to refer hereafter in the description of the accidents to which hydraulic works are exposed.

CHAPTER II.

DRAINAGE.

106. THE functions of vegetable life cannot be carried on without the presence of a certain quantity of water, inasmuch as the fluids which circulate in their tissues are almost entirely composed of the water taken up by the roots from the ground. With the exception, however, of some aquatic plants, the majority suffer from an excess of humidity; and when water is found in an agricultural district in large quantities, it is as injurious as its absence is in other cases. Thence arises the necessity for *draining* lands surcharged with water, on the one hand; and for *irrigation*, on the other. It is equally important that air should be allowed access to the roots of plants; but the operations of ploughing, harrowing, hoeing, &c., by which this object is effected, belong to the science of agriculture rather than to engineering.

107. The causes of the excess of moisture in any particular district depend upon the rain-fall, the natural configuration of the land, and the nature of the surface and the subsoils; and, conversely, the same causes influence the dryness of other districts.

108. The distribution of rain is very unequal, not only when large divisions of the globe are considered, but also over very confined areas. This is a natural consequence of the laws affecting the production of rain; for it is caused, firstly, by the heat giving rise to

evaporation, and then by the winds carrying the vapour to a distance, until it is precipitated, either by contact with the cold earth, or by meeting with another mass of air so much colder than itself as to absorb the heat which holds the moisture in solution. In the tropical regions, the rain-fall is greatly in excess of that of the temperate zones; but from the greater uniformity of temperature, it also happens that the fall is confined within a much more limited space of time; the total quantity is greater, but the number of rainy days is less, and the law appears to prevail that the number of rainy days increases with the latitude, north and south of the Equator. But local circumstances modify these general laws to a great extent; so much so indeed, that in nearly the same parallels of latitude one district may be subject to frequent floods, whilst another may be constantly, or periodically, exposed to droughts.

109. The quantity of rain, for instance, is always less on plains than it is on elevated table-lands, especially when the latter are connected with mountain chains. On the sea shore also, it is greater than in inland districts, because necessarily more vapour rises from the sea than from the land. The existence of particular currents in the ocean will at times give rise to an excess of rain on the shores round which it flows, an instance of which may be cited in the gulf stream, which causes the great rain-fall in the southern and western counties of England and in Ireland. The prevalence of certain winds will also augment or diminish the quantity of rain, according to whether they blow over surfaces able to affect in any way the amount of evaporation. Thus, in Europe, if the wind blew always from the north-east, it would never rain; whilst if it always blew from the south-west, the rain would never cease on the sea coast. It is to these

various causes that we must attribute the local differences between the number of rainy days, which, in the instance of Ireland, are about 208 out of the total 365; in that of the greater part of England, France, and the north of Germany, they vary from about 152 to 155 rainy days in the year; and in that of Siberia, it is stated that the number falls to 60. Nor are the quantities falling less variable than is the number of the days; for we find that the total quantity registered near London is, on the average, about 24·75 inches per annum; whilst near Plymouth it is about 38 inches; at Manchester, 37·5 inches; at Seathwaite, 140·6 inches; at Glasgow, 33·5 inches; and near Edinburgh, at Glencorse, in the Pentland Hills, 36·25 inches.

110. The natural configuration of the country affects the amount of moisture retained, by the greater or less facilities it may offer for its removal. Evidently, a district presenting sharp declivities on every side, with few depressions to hold water in pools, must not only throw off the latter with great rapidity, but also furnish few means of maintaining evaporation when the fall of rain shall have ceased. The outline and direction of the watercourses also materially influence the length of time during which the water may be retained. And, indeed, the majority of cases in which marshes occur may be attributed to the physical causes connected with the surface of the earth; either, in fact, to the existence of a zone of surrounding country at a higher level, or to the existence of a watercourse in a similar relative position.

111. The natures of the surface and of the subsoils produce effects upon the humidity of a district which are more readily under control than the causes previously alluded to. They act either by retaining the surface waters, or by giving passage to the springs fed

by lands at a greater distance; and it is of the utmost importance to be able to distinguish between these two sources of humidity, as the surface drainage adapted to the first, under some circumstances is utterly ineffectual to remedy the second.

For drainage operations, the strictly correct geological descriptions of the various strata may be neglected, and they may be divided simply into two classes, the *porous* and the *impervious.* The former comprises all those consisting of loose materials which absorb water easily and allow of its passing freely, such as gravel, sand, loamy clays, and the comminuted upper strata of most of the limestone formations. The latter consists of stiff blue clays, or of the plastic clays found in such abundance in some districts; of some kinds of gravel cemented by argillaceous, calcareous, or ferruginous materials; and of such limestone, sandstone, or granitic rocks as present a close grain without any fissures. No regular order of superposition of these descriptions of strata exists in nature, and from their complication arise the greatest difficulties in drainage.

112. In such cases as those in which a pervious stratum lies upon an impervious one, the water falling from the clouds permeates the former until it meets the latter. If, then, no escape be furnished by some natural overflow, the water must accumulate in the lowest depressions, until the hydrostatic pressure of that in the higher portions forces it to the surface in any lower ones whose conditions of level may be such as to allow of its rising over the surface. It may frequently happen, that a natural overflow exists at a small distance from the surface, but not at such a depth as to prevent the existence of great moisture in the main body of the stratum, although no external indication

beyond the character of the herbage may indicate the moisture. The great objects, therefore, in all drainage are, not only to remove the surface waters, but more particularly to cut off the subterraneous waters, which either rise to the surface, or are confined beneath it.

113. The removal of surface waters is a comparatively simple operation; for it may be effected by simply dressing the land into ridges, and giving these ridges an outfall into a drain or ditch all round the field. The ditch itself would pour its waters into any natural course, and the latter may at any time be enlarged or improved, by observing the principles regulating the flow of water in open channels, laid down in page 26, and subsequently, of this Treatise. The conditions to be observed being that the channel should be able to carry off, at a suitable velocity, the maximum quantity of water likely to be thrown into it within a definite period; and that the velocity should not be such as to endanger the bottom or the sides. If the outfall drain be artificially made, it is, generally speaking, desirable that it should be impermeable.

114. Operations connected with the improvement of an outfall affect very large areas, and would seem almost to call for some action of the Legislature. In many individual cases, so to speak, it is beyond the power of one proprietor to undertake them; and the only course left open to him is, to isolate his own land by diverting any water flowing from other districts, and to remove that which falls upon his own, by means the best adapted to effect that object economically. The execution of an intercepting drain will very frequently suffice to remove all the subterranean waters, should such be found, by stopping the flow of the latter in what would otherwise be their natural direction, and thus leave merely the rain-water falling over the

particular district to be dealt with. In such countries as Holland, and the fens of Lincolnshire, Bedfordshire, &c., the intercepting drain itself becomes the outfall, and a means of communication; for the main drains are used as canals, and the waters from the low lands are pumped into them either by windmills or by steam power, as may be most expedient.

115. In hilly countries it rarely happens that any difficulty occurs from the direction or inclination of the watercourses, and in them the question of outfall is not so complicated as in the lower and more level districts near the embouchures of rivers. The longitudinal section of the centre line of nearly all the rivers is, in fact, a concave parabolic curve, the apex of which is in the elevated grounds near its source. The velocity, under such circumstances, is very great in hilly countries, and the streams are able to keep their course in a tolerably straight line, if even they do not continually tend to rectify any bends which may naturally exist. But in proportion as the rivers approach the sea, or other large rivers, they usually flow through flat alluvial deposits, or through level plains of earlier formations. The velocity of the water diminishes, and the gradual deposition of matters brought down from the hills raises the bed of the river, whilst the direction becomes tortuous from the incapacity of the stream to overcome the obstacles to its progress. In no country in the world can more striking illustrations of these laws be found than in England; nor, perhaps, is there any country where well-directed works for the purpose of obviating their inconveniences would be attended with more brilliant results.

116. Before, however, commencing any rectification of the bed of a river or stream, it is necessary to in-

quire carefully into all the numerous commercial interests which are likely to be affected by the alteration. A plan of the existing watercourse and its various affluents, with longitudinal and transverse sections of the beds and banks to a considerable distance on each side, is required; observations upon the flood and summer levels, and upon the seasons and duration of the changes in the volume of the stream, must be made; and, lastly, a careful notice must be taken of the nature of the materials carried down, the mode in which shoals are formed or the banks destroyed, and the nature of the river-bed in its normal state.

117. If the stream follow a very tortuous course, a new channel in a direct line evidently would shorten the distance between its extreme points, and increase the inclination of the water line. The velocity of the stream would be proportionally augmented, and if the same quantity to be discharged flow before and after the execution of the new channel, its sectional area may be made smaller; or if, on the contrary, it be made of the same area as the original channel, it would be able to discharge a greater volume. Any sudden bends may thus be avoided; but it is to be observed, that there seems to exist some law, the cause of which has hitherto escaped our analysis, owing to which rivers are not able to flow in straight lines for any great distance, in other than beds of masonry, without requiring great and frequent repairs. At any rate, every stream when left to itself, so to speak, assumes a tortuous outline; and, from the experience obtained in France and Italy, it appears, that after a deviation there is always a tendency to resume the original directions, especially during the seasons of floods. It may, therefore, be preferable that the centre line of a new channel be formed with a series of curvatures of

very large radius, rather than in a perfect straight line. Upon the Rhine it was found that the river exercised no corrosive action upon its banks when the radius of curvature was about 2750 yards long, the bed of the river consisting of sand and gravel, and being frequently exposed to sudden and violent floods.

118. The efficient action of new channels can only be attained by observing these conditions:—Firstly.—They must be deepened as much as possible; the sectional area to be given will of course be regulated by the volume to be discharged under all the varying conditions of the rain-fall. Secondly.—They must not present any sudden projections, or form any sharp curves with the main stream. Thirdly.—If the new channel cannot be dug out at once to the required depth, it must not be opened to receive the waters until the *down* stream end of the old channel be closed, so as effectually to force all the running water into the new channel. Fourthly.—All obstacles, such as trunks of trees, large blocks of stone, &c., must be removed, so as to leave the watercourse perfectly clear.

119. When an entirely new outfall is to be formed, the dimensions to be given to it must depend upon the proportion of the rain-fall it may be required to carry off. This will vary, not only according to the configuration of the country, but also according to the greater or less degree of permeability of the materials used in its construction, and of the surface of the country itself. In precipitous mountain districts the rain flows off with comparative rapidity, merely from the inclination of the ground. Should, however, our observations be directed to particular mountain districts, it will be found that the discharge from granitic rocks differs very materially from that from the lias, the oolites, or

the clay formations. From the granites, the rain runs off nearly as fast as it falls, for the materials are non-absorbent, and the subordinate outlines do not present any depressions likely to retain the water. The lias is also, comparatively speaking, impermeable, as are also the clays; whilst the oolites, limestones, and gravels absorb water during the period of its falling, to give it out again when perhaps the supply may have ceased. In fact, the character of the discharge from the granites, the lias, and the clays, may be regarded as being of a torrential description, whilst that from the limestones is far more equable. In the former districts, it appears that about two-thirds of the rain flows off almost immediately in the natural watercourses, whilst in the latter, and in the gravel, the maximum quantity so flowing would only be one-third. Again, the proportion of the rain-fall which may require to be carried off will differ, according to the greater or less continuance of the rainy season. Thus, in winter it happens that the ground frequently becomes saturated with water at an early period, and it is advisable in such a case that any flood should be carried off as rapidly as it rises. The maximum quantity of rain which may fall within a given time becomes then a condition regulating the dimension of the outfall, of nearly as much importance as the average fall of the whole year.

120. An outfall having been secured, either by adopting or improving the natural facilities of the country, or by forming a new watercourse, if the source of the water deteriorating the quality of any land be not such as to be removed by surface drainage, an investigation of the surrounding district must be made, to ascertain the superposition of the strata, their nature, thickness, and respective inclinations; or, should any local circumstances prevent this

examination from being carried out on a sufficiently extended scale, small ditches or trial shafts should be sunk at the upper and lower sides of the district to be drained. The points of outburst of any springs must be noticed, and, if possible, their sources of supply be discovered. When these points are settled, the direction to be given to the drains must be considered; and, if possible, it would be advisable to make them follow the line of the longest fall of the ground. The depth, and the distance apart of the drains, must depend to a certain extent upon the description of crops to be raised, but more particularly upon the nature of the subsoil. For, in the first place, it is necessary to place the drains at such a depth as to obviate any danger of their materials being deranged by agricultural operations. In ordinary modes of cultivation, the minimum depth to which the ground is worked may be taken at 8 inches; in many others, the ground is moved to a depth of 18 inches; and for these reasons it is usual to place the drains, even in what is called shallow drainage, at such a depth that there shall be a distance of about 20 inches between their highest points and the surface of the ground. In the second place, if an impermeable subsoil be met with within a distance of 5 or 6 feet from the surface, such as to intercept the passage of the water in either direction, the drains ought, generally speaking, to be carried down to it; or otherwise the portions between each of them would only be imperfectly dried. The nature of the materials employed will also modify the depth of the drains; for if they be bulky, as in the case of broken stone, they must require a greater width than when tiles or tubes are used.

121. The width of the trenches will be regulated by

the depth of the drains, because the workmen require a greater space to work the deep than they do the shallow ones. At the surface the width is required to be greater than at the bottom; and in practice it is found that, for a depth of about 3 feet, it is sufficient to give a width of about 1 foot at the surface and of 6 inches at the bottom; for a depth of about 4 feet, those dimensions become respectively 1 foot 4 inches and 8 inches; whilst, for a depth of 8 feet, they become respectively 2 feet 6 inches and 1 foot 2 inches. The direction of the drains should be made as straight as possible, in order to avoid any interference with the discharge of the water; and they must be commenced by opening the lower portions of the district first. It is indispensable that a regular inclination be given, and that it should be sufficient to insure the flow of the water. A fall of about .1 in 200 will be found sufficient for ordinary cases, especially if the drain tiles be well laid.

122. There are several modes of filling in drains, employed by agricultural engineers, the principal of which are represented in the subjoined sketches.

Fig. 11.

Fig. 12.

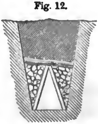


Fig. 13.

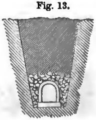


Fig. 11 represents a simple and economical system followed in countries where tubes or stones are expensive. It consists in forming shoulders upon the sides of the trenches, and laying upon them a thick sod with the grass downwards, the remainder of the

trench being filled in with the materials thrown out from it, taking care to reject the denser and more impermeable earths. This description of drain is economically formed, but it does not last for any length of time, at least with sufficient efficacy. Fig. 12 represents an economical form of drain for countries in which large quantities of water are to be removed, and where stone is cheap. The channel is formed by placing thin slabs leaning against one another on edge, and covering them with broken stones or gravel; the whole is then covered by sods and the lighter earths of the excavations, as before. If the waters draining through such channels do not contain any notable proportion of soluble salts, which they might gradually deposit around the broken stones, they will continue to flow for an indefinite period. Fig. 13 represents the tile-and-shoe drains, which were much employed in England formerly, each tile being about 14 inches long by 3 or 4 inches wide, and 4 or 5 inches high, and the shoes being of the same length, but a little wider than the tiles. Of late years, however, it has been the opinion of agriculturists, that perfectly cylindrical tubes are the most advantageous, not only on account of the greater facility of their manufacture, but also of the greater economy in their fixing. These cylindrical tubes are made of the same length as the earlier descriptions of tiles, and of diameters varying trom 1 to 3 or 4 inches.

123. When the soil is peaty, or of a running sand, or when the nature of the materials through which the excavation is carried is such as to render it difficult to form and maintain the bottom of the trench in a perfectly straight line, the abutting joints of the tubes will require to be protected by collars, which may be perforated with numerous small holes. Under ordi-

nary circumstances, it will suffice either to use pipes with an end terminating thus , or those having merely a straight end. In the last two cases, the trench should only be thrown out to the precise width necessary to receive the pipes; and in both it is absolutely necessary that the straightness and the uniformity of inclination of the bottom of the trench be rigorously observed.

124. Drains should not be made too long, because, if the fall be great there would be danger from the bursting of the pipes by the head of water; and the chances of choking are considerably increased, as well as the difficulty and expense of repairs. It is advisable to make the subdrains pour their water into a species of main drain of larger diameter, which subsequently should pour the collected stream into the general outfall. Mr. Parkes recommends that the submains should never much exceed 300 yards in length, and he usually makes the diameter of the lower half about $\frac{1}{6}$ greater than that of the upper, in order to insure the perfect discharge of the water. Under ordinary circumstances, however, it is preferable that the smaller drains should discharge into an open ditch, because the water would thence flow away more easily, and at the same time the repairs are performed with greater facility.

125. The length of the main drains may be greater, on account of their greater dimensions, but the condition above stated, of giving them an enlarged diameter at their lower extremity, must be observed. They are formed in the same manner as the subdrains, but, of course, in the lowest parts of the land; and it is advisable to place them at a slight distance below the subdrains, in order that these may discharge

more freely. Their inclination must be greater, because the volume of water they have to transmit is also greater than that of the subdrains; and it is important to carry them at some distance from the hedges, or large trees, lest the roots of the latter should force their way into the pipes and choke them; because roots are known to have a remarkable avidity for water, and are likely to force their way into the joints of the pipes. Lastly, it is important that the junction of the subdrains with the mains should not take place at right angles, but in an oblique direction, so as to avoid any interference with the velocities of the respective currents which might be likely to cause the deposition of any sand or mud in suspension in either of them. For the same reason, it is advisable, that two drains coming from different parts of the land should not be made to converge at the same point.

126. The distance apart of the drains will depend, in fact, upon their depth, and the degree of permeability of the soil; and this becomes one of the most important questions to be decided before commencing such works, for the greater the distance, evidently, the less will be the number, and the cost of the operation. Mr. Smith, of Deanstone, advocated the system of numerous drains at comparatively shallow depths; whilst Mr. Parkes and the majority of agricultural engineers now recommend that they be made deeper and at greater distances. The former made his drains from 6 to 8 yards apart, and about 3 feet deep; whilst the latter make the distance from 13 to 20 yards, and the depth from 4 feet 6 inches to 8 feet. In fact, both parties may be in error in striving to enforce their respective systems too rigorously, and a course of proceeding which may be eminently successful in one case may be very inadvisable in another. Thus, if a

stratum of permeable materials exist, whose depth may be 6 feet, it is possible that a drain placed 5 feet below the surface may withdraw the waters from a distance of about 10 or 15 yards on either side. In such a case, there would be a decided advantage in placing the drains at the greatest depths and distances, according to Mr. Parke's plan. But if the soil itself be light, and at a depth of from 2 to 3 feet from the surface an impervious subsoil be found, it would be evidently absurd to carry the drains below the subsoil, because this would entirely destroy any lateral action of the drains beyond a distance of about 6 or 8 yards. In such cases, the system recommended by Mr. Smith is the more advisable; and, indeed, it happens in this particular branch of engineering, as in all others, that every individual case requires to be judged of by, and decided upon, its own merits.

127. In Ireland the usual system latterly adopted appears to be so admirably suited to the class of materials most commonly met with, that an account of it is here given. Minor drains are formed at distances apart varying from 21 to 40 feet; the depth is made 3 feet from the lowest point of the surface; the width, from 15 to 18 inches at the top, and 4 inches at the bottom. These minor drains are parallel to one another, and only run from 150 to 200 yards without falling into either a ditch or a submain. In these drains a depth of 12 inches of broken stones, $2\frac{1}{2}$ inches in diameter, is placed, care being taken that they be quite clean; a sod 3 inches thick is placed over them, and the earth is filled in. Sometimes pipes $2\frac{1}{2}$ inches in diameter are inserted. The submains are cut 42 inches deep, by 20 inches wide at the top and 12 inches wide at the bottom; they are carried along the low side of the field, about 10 feet from the fences, and

are not allowed to run more than 300 yards without discharging into a covered or main drain. An open channel, 6 inches square, is formed, and above this the trench is covered and filled in, as before, with a thickness of about 8 inches of broken stones, carefully cleaned. The open main drains are sunk to a depth of at least 5 feet; they are made 2 feet wide at the bottom, and the sides are thrown out to an inclination of 1 to 1, if the materials be such as to stand at that inclination, excepting in rocky countries, where the sides may be left at about $\frac{1}{3}$ to 1. A minimum inclination of at least 4 feet per mile is required for these main drains. The dimensions of the covered main drains must necessarily depend upon the quantity of water they are intended to carry off; but, generally speaking, it is found to be sufficient to make them 1 foot square in the clear, with walls 6 inches thick, covered by flagstones 3 inches thick, and filled in as before.

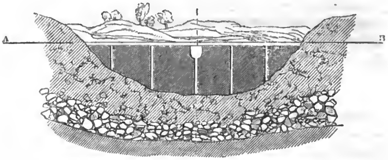
128. It appears that there is an advantage in executing the drainage of an agricultural district in dry weather, and in leaving the trenches open for a short time, in order that the ground may become warmer, and to a certain extent aërated, by being exposed to the atmosphere.

129. The measures to be adopted for the drainage of marsh lands must necessarily depend upon the causes which have superinduced this state. These causes are the following, at least in the majority of cases:—1stly, the superabundant humidity of the land may be owing to the fact that the subterranean waters are retained by beds of impermeable materials, and, after saturating the lower strata, they are forced to make to themselves a vent upon the surface; 2ndly, it may be owing to the fact that the land is situated below the level of the surrounding country, and therefore

receives the drainage from it; 3rdly, it may be owing to the existence of a river occupying a higher level than that of the marsh land itself.

130. The operations connected with drainage of large marshes, fens, or bogs, require so serious an outlay that they can only be undertaken by large companies, or by the State; but it frequently happens that small districts may be found in which a bed of clay occupies a position similar to that represented in the accompanying sketch, filling a depression upon the top of some permeable material, which last, in its turn, reposes upon a lower stratum of impermeable materials. In such cases the clay will prevent the water which

Fig. 14.



soaks through the upper and exposed portions of the permeable stratum from flowing away at the lower point. The water will then accumulate until it rises to the level of the surface of the clay, represented by the line A B, where it will overflow and form what are commonly called springs, which, unless provided with an outfall, will maintain the surface in a state of excessive humidity.

131. If, again, in the above sketch we suppose the basin-shaped depression shaded with interrupted lines to represent a bed of clay, resting upon gravel, and to

be filled in with ordinary soil, from the known impermeability of the clay it will retain all the water soaking through the soil to it, and in fact render the soil a complete morass, especially if the soil in question be surrounded by any eminences shedding their waters upon it.

132. In the illustration first supposed, the waters may be removed, either by bringing them to the surface at a point where a new and more effective outfall can be found, or by letting them escape to a lower level. In the first case, surface drains are to be cut of a sufficient capacity to hold the waters likely to rise, and transverse outfall drains made to receive them. Borings should then be made in the surface drains, descending to the top of the upholding stratum, and the hydrostatic pressure of the supply, in such portions as are placed at a higher level, will cause the water to flow into the surface drains until its level throughout the whole district will be found to be that of the drains. The outfall must be made as usual.

133. In the second illustration a boring, or borings, as may be required, are to be made through the impermeable stratum to the pervious one upon which it reposes; or, in fact, a series of absorbing wells are to be formed, and the various surface drains made to converge to it. In the Treatise upon Well-boring and Sinking much information will be found connected with the principles of the action of such wells and their mode of construction. In these instances they will serve to carry the waters from the various surface drains into the lower strata, which almost invariably will be found to possess some natural outlet, at a greater or less distance, in the shape of a spring.

134. When the succession of strata outcropping upon a hill side is more complicated than in the cases

above supposed, and is such as to produce an alternation of dry ground and marsh, the class of works to be executed may require to be somewhat different in detail, but in principle they will be found to be similar to those described. The object to be effected is, in all cases, to form a new outlet for the water; and whatever course be adopted, it must be based upon the ordinary principles of hydrodynamics applied to the particular configuration of the locality, which, again, can only be ascertained by a careful examination of the geology of the district. This examination may very frequently require to be extended over a considerable area, because the sources of supply of any springs may be found to exist at great distances, and until all the conditions affecting them are ascertained it is impossible to adopt any other than empirical methods of obviating their effects. Notwithstanding, then, the progress of science in our times, Mr. Elkington's rules may still be quoted as being the simplest and most effective for the execution of the drainage of marsh lands formed by the outburst of land springs. They are as follows:—

1st. To find out the main spring or cause of the mischief.

2nd. To take the level of the spring, and ascertain its subterraneous bearings.

3rd. To use the auger to tap the spring, when the depth of the drain is not sufficient for that purpose.

135. It must be evident, that if any district be situated so as to receive the waters flowing off from surrounding eminences, it will eventually be converted into a morass unless an outlet be provided. Should the district be small, this object may be effected, as before, by the formation of absorbing wells placed at the lowest points; but when its dimensions are con-

siderable, the first operation to be performed will consist in forming a ditch all round the marsh, so as to intercept the waters flowing from the upper lands, and at such an elevation, and with such a fall, as to insure the discharge of any waters which may be poured into it either from above, or from below. The banks, sides, and bottom of this ditch must be formed of impermeable materials. The ground contained within these banks must then be drained in the ordinary manner, and the drains made to converge to a point from which their waters may be withdrawn, either by means of an absorbing well, or by some mechanical contrivance, such as water-wheels, steam-engines, or windmills, setting in motion pumps, norias, or Archimedean screws.

136. If the marsh be owing to the existence of a river at a higher level, it must be treated in a similar manner to that just described, if the river itself cannot be diverted; or the river must be confined within impermeable banks, and the waters draining from the low lands poured into it by some of the above-mentioned engines. It may, however, happen that the stream traversing the marsh may be subject to great and sudden floods; and in such cases it is necessary to form a double row of banks, of which the outer ones must be placed at a distance, and superior elevation, sufficient to carry off the increased volume of water flowing through them at such periods. The first banks then serve to contain the river in its normal state, the second will serve to contain it during floods; the intermediate bank, or zone, may be devoted to the cultivation of aquatic plants, such as osiers, willows, &c.; or it may be drained by a separate system from that of the marsh entirely protected.

137. Of the machines used to raise water in any

of the supposed cases there are many varieties. Those hitherto applied may be stated to be—1, pumps; 2, Archimedean screws; 3, machines with buckets; 4, water-wheels with buckets, or what are called flash-wheels; 5, the water-pressure engines, hydraulic rams, rope pumps, &c.

138. Of these, the pump is the most effective when large bodies of water are to be raised from great depths, but it is exposed to the objection that the maintenance of the packing of the piston and of the pump-barrel must be very expensive when the water to be raised is so much charged with earthy matter as must always be the case with that flowing from drains. If, therefore, the height to be overcome do not exceed 15 feet, it is usual to adopt other machines. Thus, in Holland the Archimedean screw is mostly used, when the height varies from 7 to 12 feet, and in the majority of cases motion is communicated by windmills; when the height varies from 3 feet 6 inches to 7 feet, however, flash-wheels are employed. In our own fen districts the scoop has been applied by Mr. W. Fairbairn, with remarkable talent and success, in cases where the height to which the water had to be raised varied from 12 to 15 feet. In the East the noria (a machine consisting of an endless chain bearing a series of buckets, dipping into the water at the lowest point of its course, and pouring it out as it passes the upper point) has been used from time immemorial. The fifth class of machines enumerated above are so seldom used for drainage purposes that it is not worth while to dwell upon them at present. Indeed, local circumstances must modify so considerably the reasons for the choice of any one or other of these mechanical means of removing water, that it is dangerous to attempt to lay down any general law upon the subject.

The price of coals, the motive power of a neighbouring stream, the more or less favourable position of the locality so far as the action of the wind is concerned, the price of labour, and an infinite number of other details, may differ so greatly in any two given cases as to render very different modes of action necessary, or at least advisable, in the one, from the modes which would be advisable in the other.

139. Perhaps the most gigantic operation undertaken for the purpose of draining lands receiving the waters from other districts is the one lately executed for the drainage of the Harlaem Meer; and although it is rarely that engineers are required to operate upon so large a scale, a description of the method adopted is subjoined, because in principle it is identical with that which would be required even in smaller operations of the same description.

140. The Harlaem Meer, or lake, owed its origin to the excess of the rain-fall over the evaporation from the district around it, so that the waters, accumulating in the depression forming the lake, spread annually to such an extent as to absorb of late years about 150 acres per annum of its former banks. In the beginning of the sixteenth century the area was considered to have been about 9140 acres; in 1839, when it was decided to attempt the drainage of the lake, it had increased to nearly 45,000 acres, with a mean estimated depth of about 13 feet. The works have been executed by the Dutch government, who have been partially repaid by the proceeds of the sale of the land.

141. The first operation consisted in the formation of a channel for the purpose of isolating the waters of the lake from those of the surrounding country, and at the same time of serving as an outfall for the waters

to be raised. This channel is about 19 miles long, with a width varying between 125 and 138 feet, and with a depth of 10 feet, and gave rise to great difficulties owing to the want of materials fitted for its construction. Even now it cannot be said to be impermeable, and the filtrations through it must ever remain a cause of expense and probable danger. Three large steam-engines, of about 400-horse power each (nominal), raise the waters from the lake into the canal, and are stated to be able to discharge about $238\frac{3}{4}$ cubic feet per second. They are single-actioned engines, working expansively, upon the Cornish principle, and give motion to a series of pumps working at a single lift. Two smaller machines, of about 200-horse power each, are used occasionally to discharge the water from the intercepting channel, when, owing to any extraordinary tides or high winds, the natural flow from the latter is interrupted. These machines give motion to a series of flash-wheels, which raise the water about 3 feet 7 inches. The pumping was commenced, upon a large scale, in the month of March, 1849, and at the present day the whole of the surface of the lake has been brought into cultivation. The cost of these works was estimated to be, when complete, between 600,000*l.* and 680,000*l.*, or, at the higher estimate, about 15*l.* 5*s.* per acre.

142. In Ireland, some large bogs have been drained upon the system adopted in reclaiming the bog of Allen, by withdrawing the water from below, and in this case it was attended with considerable success. The surface was firstly divided into fields of an oblong figure, and of about 5 or 6 acres area, by open drains. Auger holes were driven at distances of about 33 feet down to the rock, and at a level of at least 1 foot above

the surface of the water in the drain. Curved pipe tiles, $1\frac{1}{2}$ inch diameter, were inserted into the holes, so as to throw the water into the centre of the drain. These drains were made about 6 feet deep. On the Chat Moss drainage, no effort was made to withdraw the deeper-seated waters, but all the measures adopted were designed merely with reference to those flowing upon the surface. Square inclosures were formed, 100 yards long by 50 wide, by means of large open drains, 3 feet 9 inches deep at the minimum, 3 feet wide at the top, and 1 foot 8 inches at the bottom. Covered cross drains were formed, communicating with the open ones, and with a width of between 12 and 14 inches as far as the shoulder, placed about 2 feet 2 inches from the surface; below which point they were carried to a further depth of about 16 inches, with a width of 8 inches: these cross drains were placed at distances of about 6 yards from center to center. No tiles or pipes were used, the bottom of the drain filling being formed by the surface spit raised from the moss.

143. It frequently happens that large tracts of alluvial deposits are found at the mouths of rivers, which are alternately covered or left bare by the tides, and which, generally speaking, continue to increase until they attain such a height as only to be affected by the spring tides. These banks then become covered with a species of marine vegetation, and are cut up into innumerable small creeks, which, at the low-water, serve as channels for the inshore streams. Many banks of this description have been reclaimed from the tidal action, both in our own country and in Belgium and Holland, with such signal advantage, in many cases, as to cause regret that others should still remain unproductive.

144. The works usually required to reclaim these foreshores consist, firstly, of an embankment forming an inclosure to protect them from the sea, which must be able not only to resist the hydrostatic efforts of the external waters, but also the more destructive action of the waves and the currents; secondly, of the system of drainage of the inclosed lands, including under this head occasionally the arrangements for introducing waters charged with fertilising matters, an operation performed in some districts, and known locally by the name of "warping," to be noticed hereafter (§ 181).

145. The inclosure banks are made, generally speaking, from 2 to 4 feet above the high-water line of the equinoctial spring tides, with a minimum width of from 3 feet 6 inches to 7 feet at the crown. The outline of the bank in plan must depend upon many local circumstances; but, theoretically, it will be found to offer the greatest resistance to the normal action of the waves if it be convex seawards, whilst the stability of the materials, if it be executed in stone rubble, will be the greatest if the outline be concave. Whatever be the form given in plan, it must always be borne in mind that no sharp internal angles should be allowed, and that every projection must be joined into the body of the work by gentle curves of the largest possible radius.

146. The best form of the sea slope is a subject still much in discussion amongst engineers. On the shores of Holland and Belgium the practice has been for many years to make it rectilinear, and inclined at a small angle to the horizon. Although these slopes have succeeded in some positions, there are others in which the results obtained have been precisely of an opposite character, and in which it would appear that a vertical wall would have been preferable. Again,

many distinguished engineers are of opinion that the best form to be given is one similar to the outline the materials themselves would assume if left to arrange themselves by natural causes; whilst latterly Colonel Emy has advocated, with considerable ability, the theory that a concave transverse section was the most fitted to resist the action of the ground waves.

147. Long foreslopes possess the advantage of allowing the employment of any description of sand, or other similar materials; they offer the least resistance to the action of the sea, and are precisely the less exposed to injury in proportion as their inclination is greater. It has been observed that the destructive action of the sea exercises its greatest effect about the level of the lowest high tides of the neaps. But if these long slopes possess some advantages, they are accompanied by corresponding disadvantages; for they conduct the waves to much higher points than they would otherwise reach, and it is not always that either the materials at hand or the space disposable are such as to allow of their economical execution, to which consideration, after all, the decision as to works of this description must be referred.

148. Vertical inclosure walls occupy the least space, and expose the smallest surface to the action of the waves; and these again, instead of breaking upon the shore, are reflected towards the open sea. But walls of this description must encounter the maximum effort of the waves, wherever these do strike, and their recoil must act very injuriously upon the footings, unless they be of a very resisting description. The concave walls recommended by Colonel Emy have not yet been tried in a sufficient number of cases to justify any definite conclusions as to their merits; but they

are in many cases objectionable on the score of the ground they require, and the great expense, not only of the first cost, but of the repairs.

149. The reasons which should influence the choice of the form to be given to the sea slope of an embankment may be resumed as follows:—1. It will be influenced by the main direction of the winds, waves, tides, and currents, which should be made to strike the bank as nearly as possible in a direction normal to the surface of the facing. 2. By the materials to be procured in the neighbourhood. 3. By the surface of land which can be devoted to the formation of a bank. 4. And principally, by the commercial considerations affecting the original execution, the maintenance, and the value of the whole operation.

150. The inner slope of the banks will depend upon the materials of which it is composed; and at its foot a catch-water drain must be formed to collect the

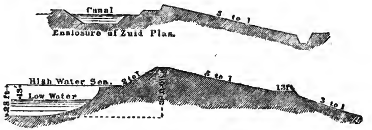


Fig. 15.—Enclosure of Zuid Plas.

waters falling upon the inclosed land, and to conduct them to the outfall. The Dutch engineers usually make the slope about 5 to 1, and they form a roadway about 20 feet wide between its foot and the edge of the catch-water drain. When the bank is formed of mud or silt, it is necessary to carry up in its center a core of sand or other hard substance, to prevent rats or moles from boring through it; and means must be

taken to cover the exposed surfaces with vegetation of a character to bind together the materials of which the bank is made.

151. The land waters collected in the outfall drain are let off by means of sluices, whose apertures will be regulated by the quantity to be discharged, and the duration of the period in which the flow can take place, as well as by the head of water which may exist at the commencement of the discharge. Upon the sea coast the intervals between the tides recur with great regularity; but in the upper portions of river-courses the casual floods are likely to prevent the discharge during periods of variable duration, so that in many such positions it is very probable that the reclaimed lands may be partially, or entirely, flooded on all such occasions: the cultivation to be adopted must be regulated with a view to these contingencies.

152. The simplest mode of closing the outfall drain is by a sluice upon hinges, fixed at the outer end of a culvert, in wood, masonry, or iron, passing through the body of the bank. The floor of this aqueduct is placed at the level of the bottom of the catchwater drain, and it has an inclination outwards. So long as the head of water upon the outside of the sluice is greater than that upon the inside, it will remain closed; directly the waters upon the outside have fallen so as to form a sufficient head upon the inside to overcome the friction of the hinge, the sluice will open and give passage to the waters. It is, however, advisable that a sliding gate working in a valve be placed behind the hinged sluice, to guard against the possibility of accidental derangements of the latter.

153. Another description of gate frequently used in these works is the gate working upon a vertical axis and shutting against a rebate, in which the areas of

the two portions of the gate are made unequal. When the waters on the outside are higher than those on the inside, the gates are pressed against the rebate; when the opposite conditions occur, the gates open and afford a passage to the land waters. Sometimes, in large gates of this description, where two leaves are employed, they are made to meet at an obtuse angle, like the leaves of a lock gate.

IRRIGATION.

154. The application of water for the purpose of assisting the growth of plants, appears to have formed an integral part of agricultural engineering even long before drainage was considered to form another part of that science. In the burning plains of Assyria, Mesopotamia, and of Asia Minor, in India and in China, and more extensively still in Egypt, works for the distribution of the great streams flowing from the mountain ridges of the great hydrographical divisions of those parts of the world have indeed existed from the earliest periods of history. It would appear, also, that the modern systems, as we proudly call them, of storeage reservoirs, both for the flood waters of rivers and for the superabundant rain-fall, were known to the engineers of the kings of Assyria, Egypt, and India; for the artificial lakes of Nitocris and Mœris, and the huge reservoirs or tanks of Bintenny, Candelay, and Mainery, which are alluded to by the earliest travellers, might still serve as lessons, or models, to our own engineers. A very interesting account of the irrigation of the nations of antiquity may be found in Jaubert de Passa's "Recherches sur les Arrosages chez les Peuples anciens," and the reader who may desire to pursue the investigation of this part of the subject

would do well to consult that learned work. For our present purposes, it may suffice to say that the principles and practice of irrigation so applied in the most ancient centres of civilisation were soon lost under the rule of the Macedonian and of the Roman conquerors of the ancient world. There are occasional references in the Latin books "De Re rusticâ," to water meadows; and the well-known passage in Virgil, "Claudite jam rivos, sat prata biberunt," evidently was inspired by the habitual practice of irrigation in the neighbourhood of the poet's birthplace, Mantua, which is still in the centre of the most perfectly developed system of that description of agriculture. But the works executed by the last masters of the ancient world for the application of water to agriculture were far inferior in their importance, and their scientific character, to those of the nations they had conquered; the irrigation channels and reservoirs of the latter were, indeed, in too many cases, allowed to fall to ruin, so that even before the northern barbaric tribes, or the Saracens, had finally destroyed the empire of the Cæsars, the wilderness had again invaded large districts which had been fertilised by the industry of the native princes. It is singular that we should thus be able to trace the loss of a science to one of the most highly civilised nations of antiquity, and perhaps more singular still that we should discover its revival amongst those whom it has been the fashion to call barbarians. But so it actually has been with irrigation; and the first records that we can discover of the systematic revival of its use are to be discovered in the history of the Gothic tribes of Italy, and amongst the Saracenic invaders of Syria and Spain. One of the most ancient irrigation canals of the Pyrenees bears indeed the name of Alaric; and even at the present day that system of agriculture is

only adopted, as an original national system, in the countries which were settled by the Goths or the Moors on the continent of Europe, or by the West Saxons amongst ourselves.

155. Without dwelling upon the progressive development of the science of irrigation, it may suffice for the purposes of this work to mention that in France, Spain, Italy, Belgium, Switzerland, Egypt, Syria, and India, many very important works have been executed at various periods for the purpose of distributing water over the land. In some parts of England, especially in the south-western counties, irrigation is much used, as it is in Northern Germany, parts of Sweden, and in America. The results obtained by the recent operations of the East India Company, in the Bengal and Madras provinces especially, have been so extraordinary, that the opinions formerly held, with respect to the most favourable regions for the application of irrigation, must be modified to a great extent; but it was at one time generally believed that the temperate zones were the most fitted for the application of the system. The most important works of this description have, therefore, been executed between the parallels of latitude 25° and 57° north; and the principles hereafter explained have been mainly derived from the examination of the results obtained in that district.

156. The object for which the execution of the works required to effect an irrigation is undertaken is, generally speaking, to increase the quantity of green food for the cattle required in a well-balanced system of agriculture; and it is therefore to meadows, whether natural or artificial, that irrigation, in temperate regions at least, is most commonly applied. In the cultivation of garden produce great quantities of water are often, no doubt, used; but the manner and

the conditions under which it is furnished are so essentially different from those which prevail when the water is led between banks (*in rigo, per rivum ago*), that the term "irrigation" cannot be used in speaking of this class of operation. It is, indeed, almost exclusively to the cultivation of green crops that irrigation is applied; for the rice grounds of warm climates may be considered to form an exception to the ordinary rule, and the following remarks will principally have reference to that description of operations. The term "natural meadows" will hereafter be used to express those meadows in which the vegetation is principally composed of the *Gramineæ*, such as the *Phlœum pratense, Lolium perenne, Festuca sylvatica, Poa pratensis;* whilst the term "artificial meadows" will be used to express those in which the *Leguminosæ* prevail, such as the *Medicago sativa, Trifolium pratense, Vicia sativa,* &c.

157. The description of soil which derives the greatest benefit from irrigation may be described, as a general rule, as being that which is the most permeable and the most easily warmed. Compact clay lands gain the least by being covered with water, because they do not easily allow that fluid to penetrate to the roots of the grasses, and they do not easily absorb or transmit the heat necessary to allow the water to produce its greatest effect; moreover, as they are very retentive, the evaporation of the water they retain near the surface positively cools the ground to a serious extent. The nature of the subsoil may, however, modify very considerably the practical application of these remarks.

158. All waters are not equally applicable to the purposes of irrigation, and great care must be exercised in their selection; that is to say, in the regions

in which irrigation performs another function than that of merely supplying the moisture necessary to enable plants to assimilate their food. This is an important observation in such cases; for, in India especially, the quality of the waters does not seem to have much influence upon the growth of the crops; but in the more temperate regions, and especially upon the artificial meadows, the chemical nature of the water becomes a matter of serious consideration. Thus, the streams which flow from forests or from peat mosses, or those which contain large quantities of the hydrous oxide of iron, are, if not positively injurious, at least but little adapted for irrigation purposes. Springs as they rise from the ground are often too cold for this use, though in Italy the *sorgenti* of the Lombard district constitute, in fact, the value of the *marcite*, or winter meadows. The waters derived from the granitic or the primary rocks, especially when the latter are characterised by the presence of large quantities of decomposable felspar, are always more advantageous than those derived from the secondary formations, on account of the potash the former usually contain. Many of the streams from the secondary formations develope the growth of the *Carex* and of the poorer description of the *Gramineæ;* whilst the waters flowing from other members of the series, such as the pure carbonates of lime, are highly favourable to the growth of the *Leguminosæ.* It is, perhaps, dangerous to lay down any invariable rule in these matters, for as the condition to be fulfilled by any irrigation water is that it should correct the natural defects of the soil it flows over, the very qualities which may be desirable in one situation might be objectionable in others. The only safe general rules, then, with respect to the choice of a

source of supply for an irrigation are, that those waters are the best which have been the longest exposed to the air, and in the proportion in which they have traversed fertile lands able to communicate some of their chemical ingredients; and it is also on account of the large quantities of fertilising matters that the waters which have flowed through large towns have thus acquired, that they become valuable as feeders to irrigated meadows. A very simple criterion, however, exists, by which the adaptation of any particular stream to the purposes under consideration may be judged, viz., the one derivable from the nature of the vegetation which naturally takes place on its banks, and on its natural bed. If these should be covered with a luxurious, vigorous herbage, and if the waters should abound in fish and mollusca, they may be considered to be fitted for the proposed use. The brackish waters of the embouchures of rivers are often highly advantageous, and cattle are known to eat the grass grown in salt-water marshes with great avidity.

159. The period of the year in which water should be poured over the land will vary, necessarily, with the latitude of the locality, and the description of crop it is proposed to raise. In very warm climates the principal function discharged by the water is to lower the temperature of the ground and to correct the drought of the climate; and evidently, in such cases, it must be applied during the summer months. In other districts, however, irrigation is expressly resorted to for the purpose of protecting the vegetation from the effects of frost, and of obviating the effects of the sudden changes of temperature which take place in the winter and in the early spring; whilst in other districts again it is an important object to retain the

alluvial matters brought down by the streams from the upper parts of their basins. To obtain the former of these objects, it is necessary to irrigate in winter; to obtain the latter, to irrigate about the equinoxes, because it is about those periods of the year that rivers are usually the most charged with alluvial matters. But there are many exceptions to these rules, dependent upon the melting of the snows on the mountain chains, or upon other conditions of physical geography; and it is also to be observed, that the very fact of the waters of a river being charged with much sediment may at times become a source of serious inconvenience; for, if a vigorous vegetation should already have grown up, the impalpable powder which would thus be deposited on the leaves of the plants would render them unfit for cattle. The time of day at which the water may be applied has also an influence upon its results, in warm weather especially. It has been observed that there is danger in applying it when the heat is the greatest; and that it is preferable to let the waters flow over the ground in the morning, or more particularly in the evening. But when irrigation is used as a preservative from frost these remarks cease to be applicable, and the water must be poured over the ground continuously.

160. If it be thus difficult to say what precise quality of water, and when it ought to be applied; it is still more difficult to say, *à priori*, what quantity is required; because the ever-varying conditions of the soil, and of the subsoil, as well as the hygrometric state of the atmosphere, must affect the solution of that problem to a serious extent. We thus find that in the Crau d'Arles the agriculturalists consider that it is necessary to pour over their lands, in dry summers, the enormous quantity of 168,000 cubic feet of water per acre, per

season of six months. In this district, the practice is to let the water flow over the land at distinct intervals, fifteen of which occur in the season; in the Haute Garonne the periods of irrigation are more numerous (they are twenty in number), but the quantity of water used is less, being 112,000 cubic feet per acre, per season. In Algeria, the French engineers calculate that a quantity equal to about 44,000 cubic feet would suffice under similar circumstances; in the eastern Pyrenees, the total quantity used per acre, in a season, is said by Jaubert de Passa not to exceed 37,000 cubic feet; whilst in our East Indian possessions the quantity usually furnished would, in the same period, amount nearly to 72,000 cubic feet per acre; or about 400 cubic feet per acre per day. Nadault de Buffon states as the result of his observations in the south of France, that the maximum quantity required during the irrigation season is about 1,200 cubic feet per day; but this calculation appears to be rather exaggerated. In our own country there would certainly be no occasion for using so large a quantity of water; and it may be of interest here to observe that in the county of Gloucestershire, the practice is to allow a stream of two inches in depth to flow over the surface, and to dress the latter with a fall of half an inch to the foot from the feeder to the drain.

161. The primary conditions for the establishment of a system of irrigation thus are, that a copious supply of water should exist at all times; and it is a matter of equal importance that the land to be irrigated should present such a configuration, as to allow the waters to flow over it with a regular current, and to insure a perfect discharge of the water after it shall have passed over the land; for directly it stagnates in the lower parts of the ground, it will develope the

growth of noxious plants. It thence follows, that in a good system of irrigation, the levels of the land must be regulated so as to ensure the following conditions: 1st, the waters must arrive by the culminating points; 2nd, they must be distributed in equable quantities, and with an equable velocity over the lower portions falling away from those points; and 3rd, they must be collected into the outfall drains, immediately after they shall have passed over the land to be irrigated. In fact, the removal of the waters is nearly as essential as their original introduction.

162. The water may be conducted to the higher points of the land by forming a bar, or dam, either wholly, or partially, across the line of the stream from which it is to be derived. Wherever it is possible, the adoption of the former course is preferable; because it allows the water to be penned back, and thus to be poured over a greater surface, and from a higher point. Should this mode of raising the surface level of the water be, however, adopted, particular attention must be paid to the possible effects of the dam in flooding lands situated above it; and it must be borne in mind, that the top water line of any intercepted stream is not a regularly inclined, though sensibly horizontal, line, but that it assumes the form of a hyperbolic curve (§ 50), which may be considered to join the natural declivity at a distance varying with the velocity of the stream. When the water is obtained from reservoirs, it is easy to regulate the precise level of the feeder, but the construction of these reservoirs requires many precautions and great practical skill. In Spain, and in India, they are often used on a very large scale, and the various reservoirs constructed in the north of England for mill purposes might, now that steam has been substituted for water power, be easily converted

for the purposes of irrigation. The discussion of the mode of forming reservoirs of this description is reserved for the division of this portion of the science of hydraulic engineering especially devoted to the subject of canals; but it may be advisable to state here, at the risk of some repetition, that the formation of the transverse dams is the most important detail of such works, and the terrible consequences of such accidents as the bursting of the Holmfirth dam, must suffice to prove the necessity for observing every possible precaution in their construction, and in preventing any infiltrations below their foundations. When these dams are constructed of earthwork, the crowns should be made of a width equal to half the clear height, and the base be at least equal to three times the same dimension. It is safer to make the principal slope on the inside; that is to say, towards the water, and to dress it into steps; and it would be preferable to make its outline in plan convex towards the water. The top should be at least two feet above the highest water line; two sluices should be placed near the bottom, one for drawing off the water, the other to allow the reservoir to be cleared; and overflows, or waste weirs, should be formed, so as to prevent the water from ever rising to the top of the dam itself. If the streams flowing into such a reservoir should be charged with very large quantities of matter in suspension during the rainy seasons, it may also be necessary to form depositing basins to receive the mud and sand they bring down.

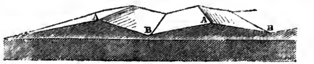
163. There are several systems for preparing the land to be irrigated, varying according to the natural configuration of the ground; but in England there are two modes of effecting this object which prevail over all the rest. These are known by the names of the

bed-work, and the *catch-water* irrigations. In the former, the land is thrown into beds or ridges, in directions, which are kept as nearly as possible at right angles to the main feeder, although that arrangement is by no means necessary. In catch-water irrigation, however, ditches are made across the declivity, at regular distances from one another, so as to catch the water flowing from the top of the field, and distribute it, again and again, over the land. The bed-work irrigation is more expensive in its first cost than the catch-water irrigation, but it is far more uniformly successful than the latter; because evidently the land over which the water flows immediately upon leaving the feeder, must receive a larger portion of the fertilizing matters it may contain than those portions receiving the water, as it were second hand. Catch-water irrigation, in fact, should only be resorted to in those positions where the declivity is too great to allow of the troughs, or distributing gutters, being made to point down the natural slope of the ground. This system is, indeed, almost exclusively practised in the hilly districts of Gloucestershire, Somersetshire, and Devonshire; although occasional illustrations of it are to be found in the northern provinces of Spain, or in the Savoy and Switzerland.

In bed-work irrigation the beds and ridges are so disposed, that a ridge may be formed having a slight longitudinal fall from the feeder, and having the ground on either side disposed with a slope towards the drains leading off the waste waters. The channels, or floating troughs, upon the ridges communicate with the main feeders, or conductors; their inclination is usually made about 1 in 500, and their length is usually limited to 70 yards; for it is considered that irrigation waters should not flow over the ground for a greater distance than the

one just mentioned, without being again restored to the parent stream. The usual dimensions of these channels is about 20 inches in width at the junction, and 12 inches in width at the end. The inclined planes on either side of the channels have a transverse inclination, varying with the nature of the soil, and the supply of water: thus in light and absorbent soils they require to be but slightly inclined, in order that the water may remain long on them, and not scour the land; whilst in compact heavy lands the rate of inclination may be increased. Generally speaking, the limits of variation, in the inclination of the sides, range between 1 in 1000 and 1 in 100, according to the nature of the ground; and the same considerations regulate the width of the planes. The more compact, indeed, is the nature of the soil, the wider may conveniently be the planes, because the water can flow upon them over greater surfaces without being absorbed; whilst in open porous soils the widths must necessarily be diminished. Upon stiff clay lands, a width of 130 feet may occasionally be given to the planes; whilst, upon porous sandy soils, 40 feet is the usual width. When the beds fall in one direction longitudinally, the crowns or ridges, A A, should be in the middle; when they fall laterally and longi-

Fig. 16.



tudinally the crowns should be made towards the upper side; and, in either case, they should project slightly above the upper edges of the planes. The dimensions and inclinations of the outfall drains, B B, at the feet of the planes must be made sufficiently

great to insure the speedy and effectual removal of the water.

164. The channels, or subsidiary feeders, receive their water from a conductor, or main feeder, which runs at right angles to them, in those cases at least wherein the supply is derived from a river which might be likely, at periods of flood, to exercise dangerous effects upon the ground, or wherein it may be considered advisable to maintain the waters under control; if, however, the stream itself should be but of insignificant volume, there can be no reason why the feeders should not be at once connected with it. The main conductor takes its origin above the weir before supposed to be placed across the stream, and should be so directed as to convey the water to all parts of the land to be irrigated; and its banks should be made a little higher than the surrounding land, so as to insure the flow of water to the latter, without its spreading laterally over the sides. Of course, the inclination and the sectional area of the conductor must be regulated mainly by the number and position of the subsidiary channels; but it is also necessary to take into account the quantity of water which may be absorbed by the earth, or lost by evaporation, during the passage of the water through the conductor. This last mentioned cause of loss may be diminished by confining the width of the canal within the narrowest possible limits. Another practical remark is also to be made, viz.: that if the river should carry down much alluvial matter, it is advisable to give the conductor a tolerably sharp fall, in order that the alluvions may not be deposited therein; an inclination of 1 or $1\frac{1}{2}$ in 10,000 will be found sufficient for this purpose in the majority of cases. An additional reason for making the conductor as narrow as possible is to be found in this

consideration, that by so doing the smallest quantity of land is occupied.

165. The formulæ by means of which the dimensions of the main conductor may be ascertained, are those already given (§ 44); and these formulæ must be applied in countries wherein water is sufficiently valuable to make it necessary to calculate its efficient distribution. The class of workmen who usually direct such operations here are, however, rarely competent to apply those rules; nor indeed, when the usual superabundance of water in our country is taken into account, would there seem to be any occasion for the exercise of so much care and skill. In Gloucestershire it is usual to make the conducting channel for a breadth of 300 acres, about 15 feet wide by 3 feet deep; and the rule is sufficiently accurate in practice for similar districts. In warm climates, and in countries where water is scarce, the strict laws of hydraulics must be applied in calculating the dimensions of the feeders.

166. At the points where the main conductor communicates with the stream, or at those where the subsidiary channels branch off from the conductors, either permanent or temporary sluices must be placed so as to be able to regulate the admission and distribution of the water at any period. Of these implements the most important is the hatch, or sluice, at the entrance of the conductor; and it will require to be of considerable strength, in order to be able to resist the effects of any sudden freshets; for if these freshets should occur when the crop is in a forward state, and be charged with much sedimentary matter, they may produce very disastrous results. The mode of closing the subsidiary channels is a matter of far less importance; and that operation may be effected

either by the use of moveable dams, or by the use simply of pieces of turf laid across their mouths. It is often necessary to place, upon the main outfall drains, hatches of the same construction as those at the head of the feeder, in order to exclude the back currents; but evidently these hatches must be opened when the irrigation is in process.

167. All the above remarks must, however, only be considered as having a very general application; and as being always susceptible of variation, according to local circumstances. Thus, the inclination frequently given to the main conductors in the mountainous districts of the Alps, Tyrol, Savoy, Dauphiné, and Pyrenees, is $\frac{1}{500}$; whilst in the private irrigation canals lately executed in Piedmont and Lombardy, it varies between $\frac{1}{1000}$ to $\frac{1}{3000}$; and in La Provence it varies from 6 to 9 in 10,000. It would appear, indeed, that in mountainous countries the higher limits of inclination may be adopted; but that if the inclination should exceed $\frac{1}{330}$, it would be necessary to retard the velocity of the stream by interposing a series of cascades, or dams, for there are very few soils which would be capable of resisting the denuding effects of the water under such circumstances. If, on the contrary, the irrigation should take place in a plain, and after the river has become tolerably clear, the inclination may, without inconvenience, be made as above stated, from $\frac{1}{1000}$ to $\frac{1}{3000}$.

168. In setting out the main conductor, it is important that the radius of curvature of the changes of direction should be made as large as possible, in order to avoid any diminution in the velocity of the flow, and in the rate of discharge; and also to obviate any destructive action upon the banks. The minimum radius should be between 100 and 150 yards. The

banks should be kept at least 8 inches above the water-line, when the supply of water is constant; and it is even desirable to make that height from 16 to 18 inches, in order to guard against any inconvenience from the growth of aquatic plants, which takes place with great rapidity in such positions. The peculiar mode of growth of this class of vegetation in long festoons, it is also to be observed, produces a greater interference with the rate of discharge of the water-courses, than would arise merely from the actual volume of the plants themselves; they retard the velocity of the flow, in fact, on account of the manner in which their long streamers follow the direction of the current; and it is important that they should be cut as often as possible. The cross section to be given to the conductor must therefore be regulated by local conditions, with a view to securing the twofold advantage of economy in the first instance, and of the minimum outlay for repairs subsequently. When the channel is cut in a hard retentive rock, it must be evident that the proper section would be one approaching a rectangular figure; in any other soil, the angle of inclination of the banks must vary with the degree of its powers of resistance. A footway should be formed on both sides of the main conductor for the purpose of examining and repairing its banks.

169. In England the supply of water is usually so copious, that it is rarely necessary to measure the quantity distributed at any particular place. In warmer climates, or even here when the preliminary expense of procuring the water has been considerable, its economical value becomes, however, so much enhanced, that it is a matter of primary importance to ascertain the quantities supplied to the various recipients. The construction of gauges has, therefore,

for a long time occupied the attention of the hydraulic engineers of Northern Italy; and the researches and experiments made by them for the purpose of establishing a simple, self-acting instrument of that description, have led to the announcement of the curious law of hydrodynamics, not before observed, to which attention has been already called (§ 51), and upon which is based the principle of the gauges used in Piedmont and Lombardy. A description of these gauges is subjoined, as they may frequently be required in our colonies, or in India.

170. The unity adopted in the measurement of water in Italy is called *l'oncia d'acqua,* and it is the quantity which could flow through a rectangular orifice, discharging freely at the lower end, but not entirely into the air, under a constant pressure of four inches above the orifice. When it is desired to distribute more than a single ounce, the width only is modified, whilst all the other conditions are retained. The

Fig. 18.

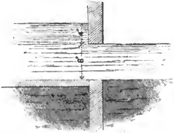


Fig. 17.

Fig. 19.

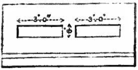
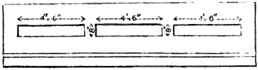


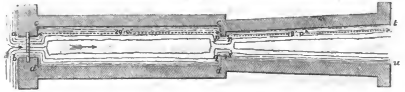
Fig. 20.



orifices of discharge are formed of the hardest description of stones to be found in the country, or occasionally of cast, or wrought iron, and are cut square

without any bevel, or the addition of anything like a funnel capable of facilitating the discharge. There are no prescriptions as to the thickness, which under these circumstances is regulated by the width of the opening; and this latter dimension is usually made of the width necessary to pass six ounces; when more than six ounces are required to be passed, the number of orifices is increased. The conductor is formed upon the banks of the canal leading from the main stream, by means of wing walls of masonry, and the sill is usually placed at the floor line. If the ground be of a soft or yielding nature, the portion exposed to the wash of the water must be paved, especially in the part where a species of cataract will exist. The opening of the conductor *a b* of fig. 21, is made equal

Fig. 21.



in width to that of the orifice of discharge, but the height is not limited. The rectangular space *c c*, *d d*, is made about 20 feet in length, and 10 inches wider on each side than the orifice of discharge, and the floor of this space is laid with a rise of 16 inches in the total length, towards the orifice *g h*. At the level *c d*, of

Fig. 22.

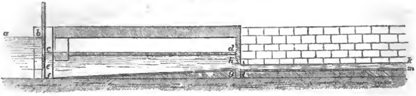


fig. 22, is a flooring, placed for the double purpose of

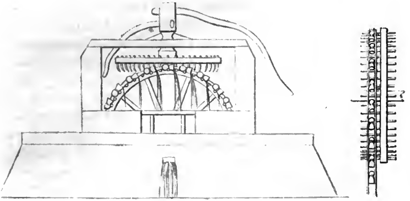
preventing the water from rising beyond the prescribed height, and for preventing any movement or agitation on its surface. The entry to this covered portion of the gauge is formed by a stone lintel, the underside of which is exactly level with the top of the orifice, and consequently 4 inches below the surface of the water; and as the height of the orifice is always 8 inches, and the rise of the inclined plane is 16 inches, the underside of this lintel is necessarily 2 feet above the sill of the sluice. Immediately beyond the orifice is the tail chamber, which is made 4 inches on each side wider than the orifice; its length is usually 18 feet, and at the further extremity its width is made 6 inches on each side wider than at the commencement. A small drip of 2 inches is formed at the commencement of the tail bay, and an inclination of 2 inches is given from thence towards the extremity. Gauges of this description require a minimum difference of level of 8 inches between the water on the respective sides of the sluice; and so cannot be applied upon canals with less than 3 feet of water.

171. It must be evident that a gauge, such as is above described, is far from being theoretically perfect. Indeed there can be no question but that the interference of the contraction of the fluid vein upon the discharge of a small orifice, must be far greater than that which takes place in a large one; and it has actually been found that the discharge through a single orifice of six ounces exceeds that which would take place through six smaller orifices of one ounce each, in the ratio of 282 to 222. For all practical purposes, however, the Italian engineers consider these gauges to be sufficiently correct; but they do not allow more than six ounces to pass through any one opening.

172. It is necessary to construct waste weirs and overflows upon the sides of the main conductor, especially when the stream from which the water is supplied is liable to sudden and considerable variations in its volume. The mode of constructing these works, as well as that of constructing the bridges, aqueducts, syphons, or other details, so closely resembles the mode adopted in canals, that their description is reserved to that portion of the work.

173. In some parts of France, and in the Milanese territory, a supply of water for irrigation has been obtained from Artesian wells; and when the spring which feeds those wells rises from a considerable depth, it is, generally speaking, of a very superior quality for the purpose in view. The higher temperature of the waters thus obtained to that of river waters, is of itself an important recommendation in their favour, and it is indeed one reason why they are principally used in Northern Italy for the "marcite," or winter meadows. At times also, the mineral elements contained in well waters are of great value; but it is

Fig. 23.



rarely that the volume they furnish is sufficient for an

extensive application. In other countries, especially in warm latitudes, mechanical means are resorted to for the purpose of raising the water to the height required; and windmills, norias (fig. 23), swapes, or *fadoufs* (fig. 24), Persian, or bucket wheels (figs. 25 and

Fig. 24.

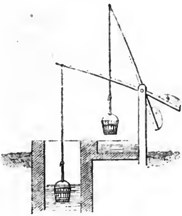
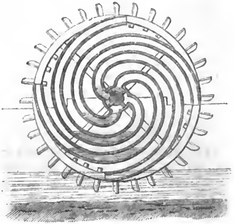
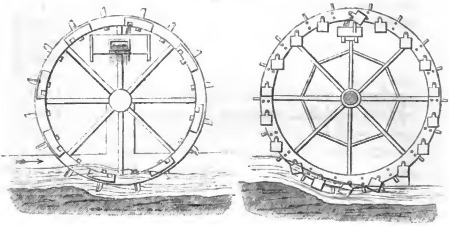


Fig. 25.



26), may frequently be seen in motion with that object.

Fig. 26.



The noria is indeed one of the characteristic instru-

ments of the Moorish agriculture, and may be observed in all the countries where the Saracens settled for any length of time; whilst the "fadouf" may be observed in the records of Egyptian civilisation recorded in their temples, or hieroglyphical writings. In our own country steam power has been applied for raising drainage waters; but, with the exception of the small works executed at Rugby for the distribution of the town sewerage, the author is not aware of the erection of any steam-engine exclusively for irrigation purposes, though there can be no doubt but that such an application would be highly profitable in many cases.

174. With respect to the application of the water, and the period of the year in which it should be poured over the land, much will, of course, depend on the latitude, and the purposes to which the irrigation is applied. In the south-west of England, the usual practice is to irrigate through the months of October, November, December, and January, from fifteen to twenty days at a time, without intermission; at the expiration of that period the water is shut off, and the ground left to dry during five or six days. If a slight frost should occur, the water is again immediately turned on; but, if there be any probability of a long continued frost, the ground is left dry. In February, the length of the periods of irrigation is diminished to about eight days, and care is taken to shut off the water early in the morning, so as to allow the ground to dry during the day time, and thus to obviate any danger from the light frosts at night. In March, the same precautions are observed; but the periods of irrigation are gradually diminished, in such proportions that the ground shall be thoroughly dry before the end of the month. The meadows are then depas-

tured during the month of April, by sheep and lambs; and subsequently eaten barely down before May by heavy stock. After the beginning of May, the grass is allowed to stand for hay, and in some districts it is usual to irrigate for a week before the grass is so left; but it appears to be an invariable rule with our farmers, not to apply more water after the grass has reached two inches in height.

175. Occasionally the meadows are irrigated after the crop of hay has been carried; but some persons consider that the grass of the aftermath is, under such circumstances, very injurious to sheep. Grass lands irrigated in summer are, in fact, known to produce the rot in those animals, though it would appear that cattle are not affected in a similar manner; just as, in the damp meadows of Holland, the cattle thrive, whilst the race of sheep is both bad in quality and liable to violent diseases of an epidemic nature. It is known also that if the purest water remain upon land for any length of time, especially in spring or summer, it would deposit a species of white scum of the consistence of melted glue, which acts very injuriously upon the qualities of the grass. All these remarks may be applied to the other countries of temperate latitudes in which irrigation is used; but of course they are susceptible of modification, according to the nature of the soil or of the crop to be raised from it. Local experience must, therefore, always be consulted in arranging the details of every work of this description. Indeed, the very interesting Reports by the able engineers connected with the Irrigation department of the East India Company's service show that very little is known, of a trustworthy nature at least, with respect to the proper or the most advantageous applications of water. Like all other

every-day sciences, that of irrigation has been hitherto treated with very little philosophy: the marvellous results of the works lately executed in India may, perhaps, lead to a more careful investigation than has hitherto taken place of the various questions involved.

176. There is one of these questions of detail which certainly merits more attention than it has hitherto received from our agricultural engineers, namely, whether or no it be necessary to manure the lands to be irrigated? It would appear, from what has been hitherto recorded, that the answer to this question would depend mainly upon the quantity of water to be distributed, upon the relative natures of the soil and of the waters. The German irrigators, who are able to dispose of large quantities of water, as we also are in England, have a popular proverb to the effect that "he who has water has grass;" but in the north of Italy, where the supply of water is limited, the universal practice is to manure the lands highly before commencing a course of irrigation. In the granitic districts of Northern Spain there does not appear to be any reason for the application of any fertilising ingredients beyond those which are supplied by the water itself; and even in parts of the Campine, or the plains near Antwerp, meadows are known to be annually improved, simply by the application of water without the addition of any manure. The grasses in our northern latitudes act, indeed, to convert the mineral and organic matters contained in the waters for their own nourishment; but in warmer latitudes the function discharged by the waters distributed by irrigation is, to facilitate the assimilation of the elements required for the growth of the plants, rather than themselves to furnish those elements.

177. Generally speaking, the turf, or the natural grass surface of a country laid out for irrigation, will suffice for the covering of the ground over which the water is to flow; but as it may occasionally be necessary to sow grasses for the purpose of, as it were, creating a new vegetation, it may be worth while to give a translation of the mixtures of seeds which are recommended by the most practical foreign irrigators for the various descriptions of soils. Thus, for sandy soils, a mixture is recommended composed of the seeds of—

1.	Phleum pratense	2 lbs.
	Agrostis vulgaris	6 ,,
	Holcus lanatus	4 ,,
	Poa trivialis	6 ,,
	Trifolium repens	12 ,,
	Medicago maculata	3 ,,
	Lathyrus pratensis	3 ,,
	Per acre	36 lbs.

2. For a sandy soil with a slight mixture of clay:

Phleum pratense	2 lbs.
Poa trivialis	6 ,,
Festuca elatior	6 ,,
Lolium perenne	4 ,,
Avena pubescens	3 ,,
Vicia sepium	2 ,,
Lotus corniculatus	2 ,,
Trifolium pratense	10 ,,
Per acre	35 lbs.

3. For calcareous soils:

Bromus pratensis	5 lbs.
Dactilis glomerata	4 ,,
Avena elatior	4 ,,
Lolium perenne	2 ,,
Poa trivialis	9 ,,
,, pratensis	2 ,,
,, augustifolia	2 ,,
Medicago maculata	2 ,,
Trifolium pratense	6 ,,
,, fragiferum	4 ,,
Per acre	40 lbs.

4. For stiff clayey soils:

Phleum pratense	2 lbs.
Alopecurus pratensis	4 ,,
Poa trivialis	9 ,,
Festuca pratensis	4 ,,
,, elatior	3 ,,
Peucedanum officinale	3 ,,
Medicago maculata	2 ,,
Trifolium pratense	10 ,,
Lathyrus pratensis	2 ,,
Vicia sepium	2 ,,
Per acre	41 lbs.

Of course it must not be considered that the attempt to fix these proportions is anything more than a rude attempt to fix the composition of the grains to be sown; and every farmer must exercise his own discretion as to the precise nature of the mixture he will employ. If sowing should be resorted to, it would appear that in our northern parts of Europe the most advantageous period for performing that operation is

about the month of March; and, for the purpose of protecting the young plants, it is customary to sow some of the cereal crops at the same time with the grasses. Oats seem to be the most useful in such cases, and they are cut in flower, to be used as fodder; or the buckwheat may be used, provided it be not allowed to shed its grain, for otherwise the new plants would run the risk of being smothered by it.

178. When water is used, as in the warmer regions of the East, for garden cultivation, the manner of its application must vary essentially from that resorted to in North-Western Europe for meadow lands, on account of the different function it has to perform. In the former case the water principally acts to refresh the vegetation and to facilitate the assimilation of its nourishment, and it is therefore made to infiltrate the ground, instead of flowing over it in a uniform stream, as is the case in water meadows. The intervals between the watering of the irrigated meadows, however, enables that class of operation to be carried on more economically (so far as the mere consumption of water is concerned) than when, as in garden irrigation, the feeding channels must be kept constantly full; and thence it happens that the latter operation is rarely performed when the supply of water is obtained from reservoirs. Wherever in the East a permanent supply has been obtained, the garden cultivation has been applied; and it might almost be said that in those regions irrigated orchards and gardens take the place of our meadows. The dry, clear, burning atmosphere has indeed there rendered irrigation necessary not only for the plants, but also for the comfort of man, and even the worst regular governments have striven to secure that blessing. In the plains of Syria, and in the dominions of the

Mohammedan kings of India, great works have thus been undertaken for this purpose; and, indeed, the engineers of our East India Company have lately had little else to do with the irrigation canals of their predecessors than to repair and slightly redress them, in order to restore their efficiency. There is one difference, however, between the irrigation provided in Syria and that of our Indian possessions, viz., that the former is almost exclusively devoted to garden cultivation, whilst the latter is occasionally applied to the growth of rice, and the enormous quantities of water which the East Indian engineers are able to dispose of have enabled them to combine other commercial applications of water with the one they principally had in view. But whilst dwelling upon this part of the subject, it may be as well to observe, that at all times, and in all climates, the tendency of irrigation is to develope in the plants receiving it a growth of the leaves at the expense of the fruit or grain. This is especially the case in warm climates, where all the operations of nature take place on an extended scale; but the effect of the law is to exclude cereal crops from the system of agriculture in irrigated districts, unless the cereals themselves should be of a peculiar nature, such as the rice, and perhaps also the Indian corn. Moreover, although in India the great feeders for irrigation, canals, are at times made to facilitate a species of canal navigation, and to drive mills, the economical results of such mixed systems have hitherto been more than questionable.

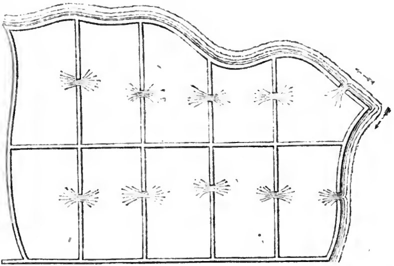
179. In the warmer latitudes, as has been before observed, water is largely used for the purpose of creating artificial rice-grounds, and the conditions of the growth of that plant, as well as those of the application of water to it, are sufficiently distinct from

the conditions which prevail in ordinary irrigation to justify a passing reference to them. Now, the rice is essentially an aquatic plant, and it only grows in latitudes situated below the parallel of 46° north. During its growth it requires to be constantly immersed in water; and it would seem that the quality of the land upon which it is grown, is a matter of far less importance than that of the water employed; and that the water is by so much the more fitted for the irrigation of rice fields, as it is charged with the greater quantity of extraneous matter. For this reason river and pond waters are preferable to spring waters; and indeed, the coldness and purity of the latter are at times so objectionable in rice fields, that it is considered necessary to expose them in shallow reservoirs, and to mix them with animal manure before pouring them upon the land. It is usually calculated that the quantity of water required to irrigate a rice field, is about 1 cubic foot per minute, and per acre. This style of cultivation may either be permanent, or it may form part of a rotation; in the first case it is adopted because the land is marshy, either from the want of outfall, or from the springs rising in it; in the second, a species of artificial irrigation is required for every crop of rice which is to be raised from the land.

180. Whatever may be the nature of the ground to be converted into rice lands, the first condition required is, that the water should be kept continually in motion, and that all of it which is brought upon the land should be removed. A series of plane surfaces must thus be formed, so that no part of the land may be left dry, and that the water may not be allowed to stagnate in any part. After the land has been properly levelled, it is to be ploughed, and then the

retaining banks are to be formed; of these there are two sorts: 1st, the longitudinal ones, or those which have the same direction as that of the stream, and which are intended to last as long as the field is laid down in rice; and 2nd, the transverse banks, which intercept the current in an angular direction; so that when the banks are completed the rice field will be divided into a series of polygons. The sizes of these polygons is principally regulated by the difference of levels of the planes themselves; and they are made the smallest in those cases wherein the inclination is the greatest, in order to economise the labour of disposing them in horizontal planes. Moreover, the dimensions of these fields are limited by the consideration that the larger they are, the greater probability there must be that the wind may tear up the young plants. It is usual to make the banks about 6 inches

Fig. 27.



above the ground on the upper side of the field, and about 2 feet above that level on the lower side; the

width is never less than 6 inches at the crown; but as the top of the banks often serves for a road, as well as for the immediate object of their formation, the width may vary indefinitely. They are made with the earth taken from the lower parts of the field; and when they are roughly terminated, the water is let into the first division and allowed to rise about 5 inches all over the surface. Openings are then made in the lower banks, and water is successively let into them, so that, in fact, the whole of the field is converted into a succession of small ponds, separated by the several banks. During the whole of the growth of the plant, it is thus exposed to be irrigated by flooding; but the extent and the manner of this flooding will vary with the health of the plant, its degree of maturity, and the violence of the wind. It becomes, therefore, necessary to regulate the admission of the water in such a manner as to be able to control its flow at any moment; and even occasionally to shut it off entirely. After the rice crop has been carried, all the water is withdrawn, and the land is left exposed to the action of the atmosphere throughout the winter, and until the spring.

181. Before closing this chapter it may be worth while to call attention to two modifications of the system of irrigation which are often of great local value. The first of these is known in the eastern counties of England by the name of "*warping;*" and it is, of course, under other names, largely practised abroad, whenever the natural water courses are highly charged with mineral substances in suspension. Upon the banks of the Humber, and in some parts of Holland and Northern Germany, upon the banks of such rivers as the Ganges and the Nile, it is customary to form enclosures, in which the waters of the rivers are retained, in order to deposit the alluvial matters

they contain. But there is this singular difference between the conditions under which the rivers of Northern Europe, usually employed for warping, deposit their alluvions, from those prevailing in the mighty streams named above in conjunction with them; viz. that the alluvial matters deposited by the former are mostly brought in from the sea; whilst those brought by the Nile and the Ganges, are almost exclusively furnished by the disintegration of the lands near their sources. Warping in the former case, can only take place near the sea; in the latter it may, and does often, take place throughout the whole course of the rivers; and the quality of the land so irrigated is necessarily affected by the salts or other ingredients which are obtained from the waters.

182. It is usual to surround land proposed to be thus treated by an embankment, in which are placed the inlet sluices, at the lowest level. The water enters through these sluices at the highest point of one tide, and is retained during the interval between two successive tides; to be then run off entirely, even from the ditches, before the influx of the next. Upon the banks of the Humber it is considered that the most beneficial effects are produced by the execution of this operation between the months of June and September; the embankments are made from 3 feet to 7 feet high, and it is usually calculated that a sluice, with a clear water way about 6 feet high and 8 feet wide, will suffice to warp a surface of from 60 to 80 acres. In this district it is found that the warped lands are at first cold and raw, and that they require a peculiar treatment for agricultural purposes. Thus, they are not favourable for the growth of corn; oats may succeed upon them, but barley never will. The rotation usually adopted is as follows:—The new warp is sown

with grass for two years; on the third year wheat is sown; on the fourth, beans; and on the fifth, wheat again. Should the ground thus warped be found to contain too much salt, it must be exposed to the air for some time before being brought into cultivation; and at all periods it is found to be objectionable to allow the salt warp to deposit upon growing grasses. Indeed, in Yorkshire, it is customary to let the newly-warped land lie fallow for twelve months before sowing the grass, and to let on the waters after the second crop of wheat has been raised.

183. The quantity of sediment brought down by the rivers falling into the Humber is enormous. Lord Hawke stated, in his Report on the Agriculture of the West Riding, that one tide would deposit an inch of mud, and the source from whence it is derived is still a matter of great uncertainty. At its mouth the Humber is as clear as most rivers, and the floods from the upper countries, so far from increasing the quantity of matters in suspension, on the contrary, exercise a very injurious effect upon them. In the driest seasons and the longest droughts it is found to be the best and most plentiful, and produces its effect totally irrespective of the subsoil. In fact a new soil is formed, and the operation of warping differs in this respect from ordinary irrigation, which acts by improving the soil already existing.

184. The second system of irrigation referred to in § 181 is a system which acts principally by infiltration, and is applied in hilly districts as much for the purpose of obviating any ravinement, so to speak, of the vegetable soils on their inclined slopes, as it is for the purpose of irrigation strictly speaking. The feeders are in this case made as horizontal as possible, and the banks are raised, so that the water shall not flow over

the sides; but it is allowed to permeate the soil in a manner dependent of course upon the character of the latter. In Devonshire, &c., as was before said (§ 163), a modification of this system is adopted, under the name of the *catch-water meadows*, which consists in allowing the water to flow over the edge of the lower sides of the feeders in a small shallow stream, to be collected in a series of parallel lower horizontal feeders which retard its velocity, and retain any vegetable or alluvial matters the waters might remove. A drain is usually carried from the top to the bottom of a meadow of this description, at right angles to the feeders, for the purpose of removing the water from them if required; but the entrances to these drains are closed when the irrigation is to be effected. Catch-water irrigation, it may be added, is executed at a much cheaper rate than any other. For it is usually calculated that the first cost of laying down any large area on a system of bed-work irrigation is about 10*l.* per acre, whilst that of a system of catch-water irrigation is only about 5*l.* per acre. In the case of the Duke of Portland's celebrated water meadows at Mansfield, the total outlay was not less than 30*l.* per acre; but as it is tolerably well known that the enhanced value of irrigated land, as compared with ordinary land, is not less than from 1*l.* 10*s.* to 2*l.* per acre, it is strange that so little attention should at the present day be paid to the subject. In India, the irrigation works have yielded at least from 40 to 60 per cent. on the outlay; and though we cannot expect in England to obtain equally brilliant results, there is no reason to doubt but that operations of this description would still be eminently successful. The irrigation of the barren sands of the Campine, by the waste waters of the canal from the Meuse to the Scheldt, it would have been supposed would have

induced the persons interested in the suffering canal property of England to examine whether the sale of their waste waters might not compensate to them in some manner for the destruction of their carrying trade by the railways. The old Dutch engineers, who designed the irrigation of the valley of the Itchen, in Hampshire, made a very creditable attempt to apply a mixed system of canal and irrigation works, that is to say, when the state of the science of applied hydraulics in their day is taken into account; and, not to leave the county of Hampshire itself, it must appear strange that the Basingstoke canal proprietors have not attempted to apply the lesson they might have learnt from their predecessors.

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